Water Quality Report: 2006 Wachusett Reservoir and Watershed

March 2007

Massachusetts Department of Conservation and Recreation
Division of Water Supply Protection
Office of Watershed Management

ABSTRACT

The Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management (formerly known as the Metropolitan District Commission Division of Watershed Management) was established by Chapter 372 of the Acts of 1984. The Division was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the new Office of Watershed Management. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2006 water quality data from the Wachusett watershed. A report summarizing 2006 water quality data from the Quabbin and Ware River watersheds is also available from the Division.

Acknowledgements:

This plan was prepared by several staff of the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management. Principal authors are Lawrence Pistrang, Environmental Analyst, Wachusett/Sudbury Section and David Worden, Aquatic Biologist, Wachusett/Sudbury Section. Internal review was provided by Pat Austin. Frank Battista, David Worden, Paula Packard, Kelley Freda, and Lawrence Pistrang collected the samples and were responsible for all field measurements. All analyses were done by the MWRA.

DCR/DWSP/OWM thanks the staff and management of the MWRA Deer Island Lab for preparing and delivering sample bottles and performing all nutrient and metal analyses during the year. They also thank MWRA staff at the Southboro Lab for completing all routine and special coliform analyses during the year.

All maps in this report were produced by DCR/DWSP/OWM GIS analyst Craig Fitzgerald using the most recent data.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

WATER QUALITY REPORT: 2006
WACHUSETT RESERVOIR AND WATERSHED

1.0 INTRODUCTION

The Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management (originally known as the Metropolitan District Commission Division of Watershed Management) was established by Chapter 372 of the Acts of 1984. The OWM was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

The Surface Water Treatment Rule requires filtration of all surface water supplies unless several criteria are met, including the development and implementation of a detailed watershed protection plan. The OWM and the MWRA have a joint waiver from the filtration requirement and continue to aggressively manage the watershed in order to maintain this waiver. Water quality sampling and field inspections help identify tributaries with water quality problems, aid in the implementation of the OWM watershed protection plan, and ensure compliance with state and federal water quality criteria for public drinking water supply sources. Bacterial monitoring of the reservoir and its tributaries provide an indication of sanitary quality and help to protect public health. OWM staff also sample to better understand the responses of the reservoir and its tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the reservoir and the watershed.

Routine water quality samples were collected from a total of fifty-four stations on thirty tributaries and from three stations on the reservoir, a continuation of the intensified sampling program initiated in 2004. Weekly or twice weekly collection of Wachusett Reservoir plankton was done from the back of the Cosgrove Intake or from a boat at Station 3417 (Basin North) in order to detect increasing concentrations (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Temperature, pH, dissolved oxygen, and conductivity profiles were taken in conjunction with plankton sampling; quarterly profiles were also measured at two additional reservoir stations. Fecal coliform samples were collected from twenty-three reservoir surface stations, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations.

Samples were also collected from a number of additional locations to investigate potential water quality problems that were discovered during Environmental Quality Assessment fieldwork and investigations. Water samples were collected during both dry and wet conditions, usually from several locations on a single tributary, to help locate pollution sources. Samples were collected from Asnebumskit Brook, Beaman Pond Brook, and Cook Brook in 2006. Composite samples were collected from a storm event in April to document water quality of stormwater runoff. Several additional samples were collected at potential point sources during the year.

All fecal coliform, conductivity, turbidity, and associated precipitation data collected are stored in a DCR electronic database (Microsoft EXCEL file fc_dbase2006.xls) on the w: drive of the DCR server in West Boylston. Nutrient data reside on the MWRA LIMS and in DCR electronic files at West Boylston. An electronic file of plankton data is also maintained on site in West Boylston. All data generated during tributary and reservoir water quality testing are discussed by parameter in sections 3.1 – 4.4, and all data are included as appendices to this report.

The Pinecroft Area drainage basin continues to be investigated to document the positive impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling in 1998 established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small urbanized subbasin at the headwaters of Malden Brook prior to sewer construction. [Note: This area previously was considered the headwaters of Gates Brook but drainage patterns have changed following highway construction and an in-depth hydrologic investigation has established that flow enters the Malden Brook subbasin.] Samples were also collected in two similarly sized subbasins with different land uses (agriculture, undeveloped) for comparative purposes. Weekly sampling of the three subbasins has continued through 2006. Almost 75% of the homes in the Pinecroft neighborhood are now connected to the municipal sewer and water quality in the subbasin appears to have improved somewhat, although a significant decline was observed in 2005 and investigations into other possible sources of contamination are ongoing. An analysis of the data collected as part of this study is included in this report.

Environmental Quality staff continued to monitor site-specific impacts of development on water quality. Ongoing communications with state and local officials helped ensure implementation of best management practices, remediation of existing problems, and quick notification of imminent threats. Staff attempted to communicate with conservation commission and board of health members on a regular basis to provide technical assistance and to gain advance knowledge of proposed activities. Regular attendance at conservation commission, planning board, and board of health meetings was resumed during 2006. All investigations and projects were documented as part of a comprehensive filing system and an ACCESS database of the files is located on the w: drive on the DCR server in West Boylston .

In an effort to refine the process of threat assessment within the Wachusett watershed, Environmental Quality staff divided the watershed into five sanitary districts with the goal of completing a detailed assessment of one district per year on a five-year rotating basis. The Stillwater District Environmental Quality Assessment was published under separate cover in the spring of 2006. During the remainder of the year information was gathered on hydrology, natural resources, demographics, land use, historic water quality, and both actual and potential threats for the subbasins within the Worcester District. A district overview with detailed information was prepared, and both general and specific recommendations developed, and a draft of the Worcester District Environmental Quality Assessment was produced at the end of 2006.

2.0 DESCRIPTION OF WATERSHED MONITORING PROGRAM

Wachusett Environmental Quality staff collected routine water quality samples from fifty-four stations on thirty tributaries and from three stations on the reservoir during 2006. The stations are described below in Table 1 and are located on Figure A. Additional stations were sampled occasionally to support special studies or potential enforcement actions. Only some of the samples were analyzed in-house, including 2384 turbidity samples and 366 plankton samples. A total of 2659 physiochemical measurements of tributaries (temperature and specific conductance) were done in the field, with another 6960 (temperature, specific conductance, dissolved oxygen, and pH) recorded on the reservoir. In addition, 3426 samples were collected and delivered to the MWRA laboratory in Southboro for fecal coliform analysis, and 112 samples were collected and shipped to the MWRA Deer Island laboratory for 1576 analyses of nutrients and metals.

Each tributary station was visited weekly throughout the entire year, although samples were not collected at some stations during low flow or no-flow conditions. Temperature and conductivity were measured in the field using a YSI Model 30 conductivity meter and samples were collected for fecal coliform and turbidity analysis. All fecal coliform analyses were delivered to the MWRA Southboro Lab for filtration. Turbidity samples were analyzed at the DCR West Boylston Lab using a HACH 2100A meter. Samples were collected in April, May, June, July, October, and December from nine stations and analyzed at the MWRA Deer Island Lab for alkalinity, conductivity, nitrate-nitrogen, nitrite-nitrogen, ammonia, total phosphorus, total silica, dissolved silica, UV-254, total suspended solids, and total organic carbon. Monthly samples for the same parameters plus metals were collected from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Depth measurements were done at these stations to calculate flow using previously established rating curves. All sample collections and analyses were conducted according to Standard Methods for the Examination of Water and Wastewater 20th Ed. (Table 2).

Precipitation data from NOAA weather stations in Worcester and Fitchburg, from the USGS station on the Stillwater River in Sterling, and from two staff monitored rain gauges in Princeton and West Boylston were collected daily to help interpret water quality data and determine if problems were related to stormwater contamination.

Temperature, dissolved oxygen, pH, and conductivity profiles were usually measured each week at Station 3417 (Basin North) or the Cosgrove Intake in conjunction with routine plankton monitoring, and quarterly at Station 3412 (Basin South) and Thomas Basin. Quarterly samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, silica, dissolved silica, alkalinity, total phosphorus, and UV-254 were collected at the same stations from the epilimnion, metalimnion, and hypolimnion and analyzed at the MWRA Lab at Deer Island.

MWRA personnel collected a regulatory fecal coliform sample from the new John J. Carroll Water Treatment Plant at Walnut Hill in Marlborough five times per week and also collected a weekly sample from the Cosgrove Intake in Clinton to maintain the historical record. Fecal coliform samples were collected once, twice, or four times per month at twenty-three reservoir locations (Figure B) by DCR Environmental Quality staff to document the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on birds and bacteria concentrations.

TABLE 1 (part one of two)

ROUTINE WACHUSETT SAMPLING STATIONS – 2006

STATION	LOCATION	FREQUENCY
1. Asnebumskit (Mill)	upstream of Mill Street, Holden	W
2. Asnebumskit (Prin)	upstream of Princeton Street, Holden	W
3. Ball Brook	Route 140, Sterling	W
4. Beaman 2	Route 110, W. Boylston (homes)	W
5. Beaman 3	Route 110, W. Boylston (muskrat)	W
6. Beaman 3.5	Route 110, W. Boylston (horses)	W
7. Boylston Brook	Route 70, Boylston	W
8. Chaffins (Malden)	Malden Street, Holden	W
9. Chaffins (Poor Farm)	Newell Road, Holden	W
10. Chaffins (Unionville)	Unionville Pond outlet, Holden	W
11. Chaffins (Wachusett)	Wachusett Street, Holden	W
12. Cook Brook (Wyoming)	Wyoming Street, Holden	W, Q2
13. East Wachusett (140)	Route 140, Sterling	W
14. East Wachusett (31)	Route 31, Princeton	W
15. East Wachusett (Bull)	Bullard Road, Princeton	W
16. French Brook (70)	Route 70, Boylston	W, Q2
17. Gates Brook (1)	Gate 25, W.Boylston	W, Q2
18. Gates Brook (2)	Route 140, W.Boylston	W
19. Gates Brook (3)	Worcester Street, W.Boylston	W
20. Gates Brook (4)	Pierce Street, W.Boylston	W
21. Gates Brook (6)	Lombard Avenue, W.Boylston	W
22. Gates Brook (9)	Woodland Street, W.Boylston	W
23. Hastings Cove Brook	Route 70, Boylston	W
24. Hog Hill Brook	Laurel Street, W.Boylston	W
25. Houghton Brook	Route 140, Sterling	W
26. Jordan Farm Brook	Route 68, Rutland	W
27. Justice Brook	Route 140, Sterling/Princeton line	W
28. Keyes (Gleason)	Gleason Road, Princeton	W
29. Keyes (Hobbs)	Hobbs Road, Princeton	W

W = weekly (bacteria, temperature, conductivity)
Q2 = quarterly+2 (nutrients- April, May, June, July, October, December)

TABLE 1 (part two of two)

ROUTINE WACHUSETT SAMPLING STATIONS – 2006

STATION	LOCATION	FREQUENCY
30. Keyes (Onion)	behind Quik-Stop, Route 140, Princeton	W
31. Malagasco Brook	West Temple Street, Boylston	W, Q2
32. Malden Brook	Thomas Street, W.Boylston	W, Q2
33. Muddy Brook	Route 140, W.Boylston	W, Q2
34. Oakdale Brook	Waushacum Street, W. Boylston	W
35. Quinapoxet River (CMills)	Canada Mills, Holden	W, M
36. Quinapoxet River (dam)	above circular dam, W.Boylston	W
37. Quinapoxet River (Mill St)	Mill Street, Holden	W
38. Rocky Brook	Beaman Street, Sterling	W
39. Rocky (E Branch)	Justice Hill Road, Sterling	W, Q2
40. Scanlon Brook	Crowley Road, Sterling	W
41. Scarlett Brook	Worcester Street, W.Boylston	W
42. Scarlett (Rt12)	Upstream of Walmart, W. Boylston	W
43. Stillwater (62)	Route 62, Sterling	W
44. Stillwater River (SB)	Muddy Pond Road, Sterling	W, M
45. Swamp 15 Brook	Harris Street, Holden	W
46. Trout Brook	Manning Street, Holden	W
47. Warren Tannery Brook	Quinapoxet Street, Holden	W
48. Waushacum (Conn)	Jewett Road, Sterling	W
49. Waushacum (filter)	above filter beds, Route 12, Sterling	W
50. Waushacum (Fairbanks)	Fairbanks Street, Sterling	W
51. Waushacum (Pr)	Prescott Street, W.Boylston	W
52. Waushacum (WWP)	Gates Road, Sterling (pond outlet)	W
53. West Boylston Brook	Gate 25, W.Boylston	W, Q2
54. Wilder Brook	Wilder Road, Sterling	W
A. 3409 (Reservoir)	Cosgrove Intake	W, Q
B. 3417 (Reservoir)	mid reservoir by Cunningham Ledge	W, Q
C. 3412 (Reservoir)	mid reservoir southwest of narrows	Q
D. TB (Reservoir)	Thomas Basin	Q

W = weekly (bacteria, temperature, conductivity [tributaries], algae and profiles [Cosgrove or 3417])
M = monthly (nutrients and metals)
Q = quarterly (algae, profiles, nutrients [reservoir])
Q2 = quarterly+2 (nutrients- April, May, June, July, October, December)

Figure 1

Sampling Stations

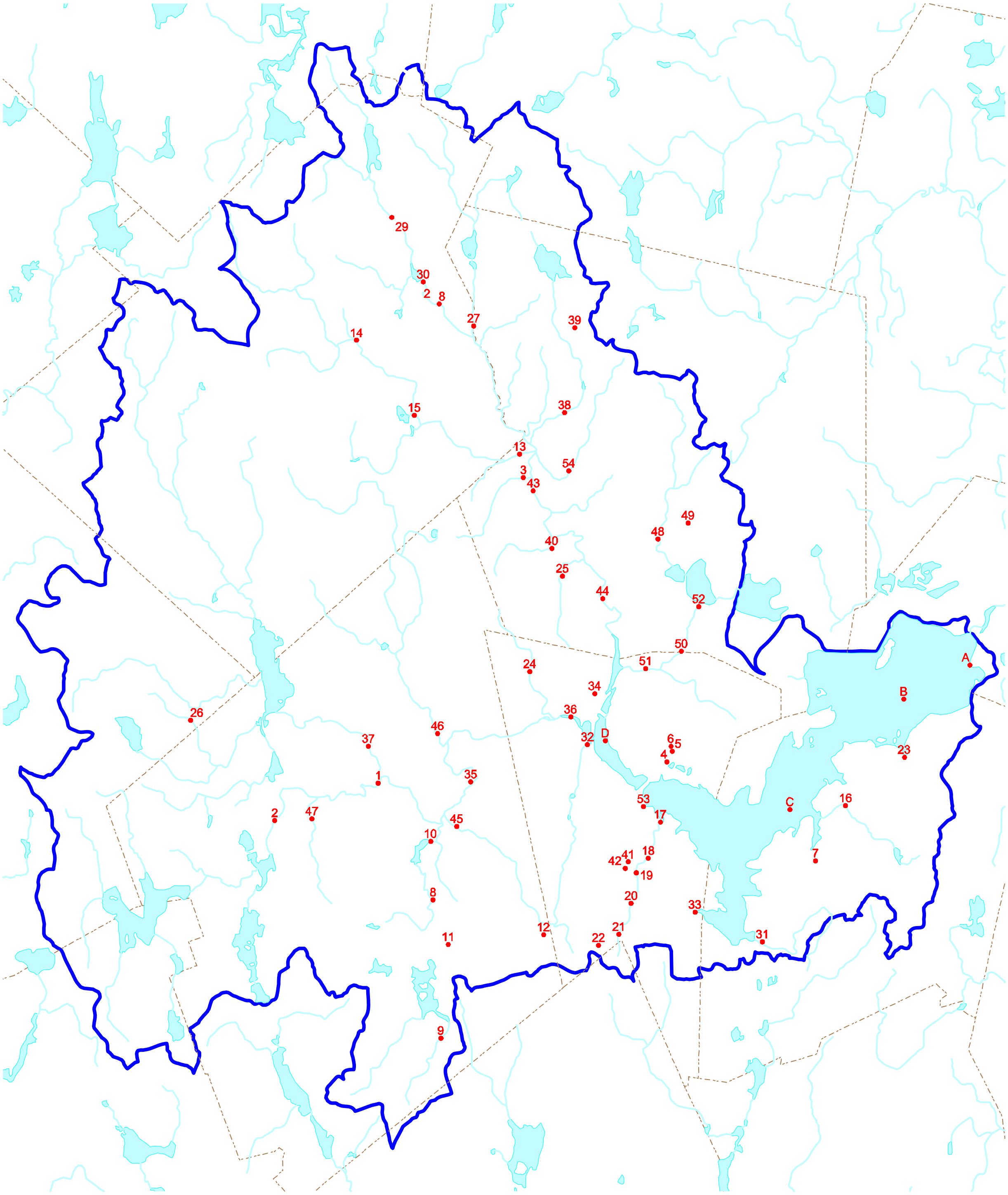


FIGURE B

RESERVOIR TRANSECT STATIONS

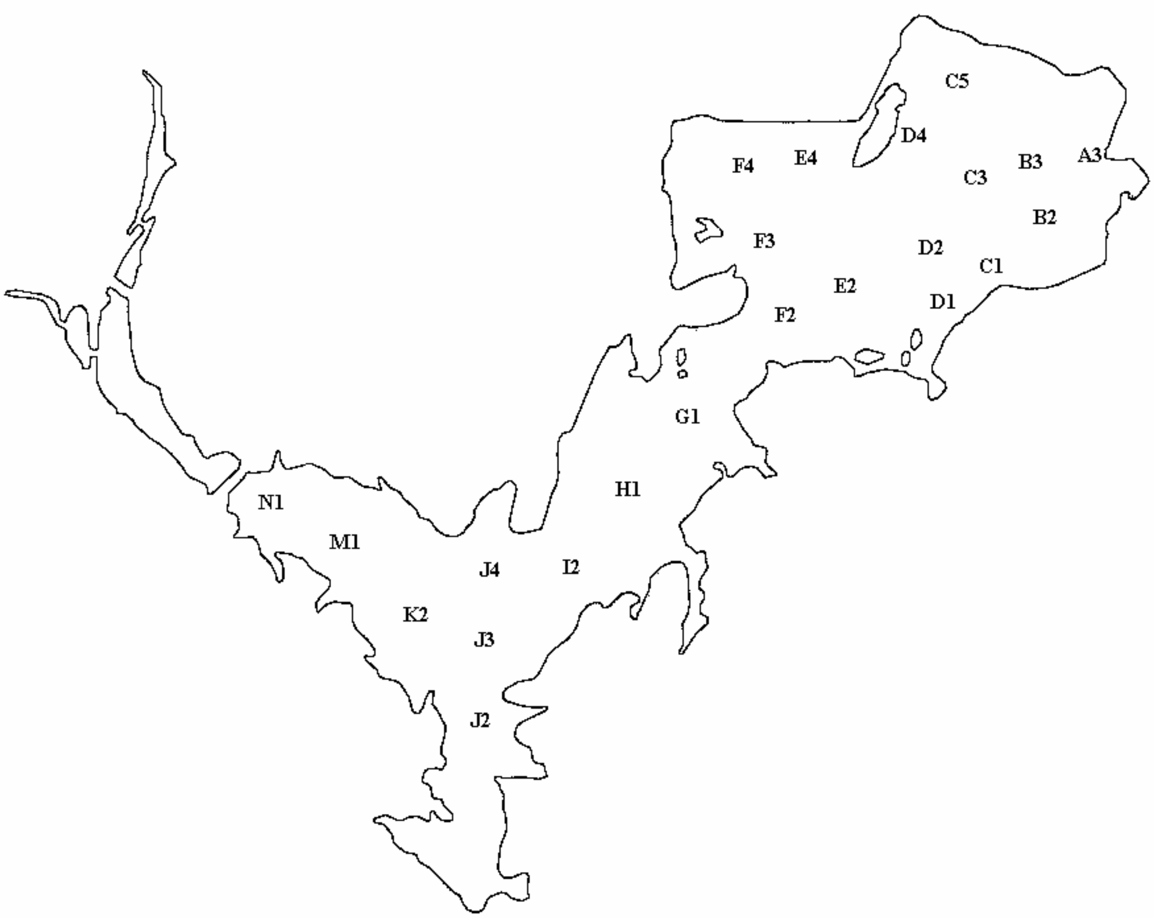


TABLE 2

METHODS USED FOR FIELD AND LABORATORY ANALYSIS
WACHUSETT/SOUTHBORO/DEER ISLAND LABORATORIES

PARAMETER	STANDARD METHOD
pH	Hydrolab Surveyor III
Conductivity	YSI Model 30 meter Hydrolab Surveyor III
Temperature	Hydrolab Surveyor III YSI Model 30 meter
Dissolved Oxygen	Hydrolab Surveyor III
Total Phosphorus	EPA 365.1
Ammonia-Nitrogen	EPA 349.0
Nitrate-Nitrogen	EPA 353.4
Total Kjeldahl-Ntrogen	EPA 351.2
Silica	EPA 200.7
Dissolved Silica	EPA 200.7
UV254	SM 5910A SM5910B
Alkalinity	EPA 310.1 SM 2320B
Turbidity	SM2130B
Fecal Coliform	SM 9222 D
Plankton	SM 10200 F

SM = Standard Methods for the Examination of Water and Wastewater - 20th edition, 1999

3.0 RESULTS OF TRIBUTARY MONITORING PROGRAM

3.1 BACTERIA

Fecal coliform concentrations were measured as an indicator of sanitary quality. Coliform density has been established as a significant measure of the pollution and has been used as a basis of standards for bacteriological quality of water supplies for some time. Fecal coliform are defined in Standard Methods for the Examination of Water and Wastewater - 20th edition (1999) as a subset of total coliform bacteria that produce blue colonies on M-FC media when incubated for 24 hours at 44.5° C. Fecal coliform bacteria are found within the digestive system of warm-blooded animals and are almost always present in water containing pathogens. Fecal coliform are relatively easy to isolate in a laboratory, and direct counts can be made using membrane filtration. The presence of coliform bacteria in water suggests that there may be disease-causing agents present as well.

Fecal coliform concentrations were measured weekly at all tributary stations. The Massachusetts Class A surface water quality standards established at 314 CMR 4.00 state that "fecal coliform bacteria shall not exceed an arithmetic mean of 20 colonies per 100 mL in any representative set of samples, nor shall more than 10% of the samples exceed 100 colonies per 100 mL". Using a yearly arithmetic mean, the standard of 20 colonies per 100 mL was exceeded at fifty of fifty-four tributary stations (93%). Hastings Cove Brook, the Quinapoxet River (Mill Street), Rocky Brook (East Branch), and Waushacum Brook (West Waushacum Pond outlet) were the only stations had an annual mean value less than the standard. Only thirty-two stations had more than 10% of the samples collected with more than 100 colonies per 100 mL, however, which strongly suggests that mean values were once again elevated by a small percentage of high measurements and that arithmetic mean is not a useful measure of annual bacteria data. One or two high values can markedly elevate the annual mean of a relatively small data set, and fecal coliform values often increase by several orders of magnitude following storm events or during periods of high groundwater. An alternate way of looking at summary data should give a better representation of actual conditions in these tributaries throughout the year. The use of median values to represent water quality has been used for many years by Environmental Quality staff, and the DEP changed Class A standards in early 2007 to utilize geometric mean as the new standard. The geometric mean, unlike an arithmetic mean, dampens the effect of very high or low values which might otherwise bias the mean if an arithmetic mean were calculated. The geometric mean is a log-transformation of data which usually allows meaningful statistical evaluations. Table 3 on the following page includes annual mean, annual median, and geometric mean values for fecal coliform data in the tributaries.

Supporting precipitation data from the NOAA weather stations in Worcester and Fitchburg, from the USGS station on the Stillwater River in Sterling, and from two staff monitored rain gauges in Princeton and West Boylston were used to interpret fecal coliform data by helping segregate water quality samples impacted by storm events from those more representative of baseline conditions. Storm events continue to have a significant impact on fecal coliform concentrations in most tributaries. A storm event was defined as precipitation of greater than 0.2 inches that occurred within twenty-four hours of sampling, as most impacts were no longer noticeable after that period. The effect of storm events on both mean and median fecal coliform is addressed.

TABLE 3 (part one of two)

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN (2006)	MEDIAN (2005)	GEO MEAN	SAMPLES
Asnebumskit (Mill)	640	<10	78	20	23	25	51
Asnebumskit (Prin)	>6800	<10	827	360	60	228	51
Ball Brook	520	<10	32	10	10	13	47
Beaman 2	>2000	<10	162	50	30	38	39
Beaman 3	>2000	<10	336	80	30	57	37
Beaman 3.5	3200	<10	411	130	40	86	39
Boylston Brook	>2000	<10	91	10	10	17	50
Chaffins (Malden)	540	<10	54	10*	20	19	51
Chaffins (Poor Farm)	340	<10	55	20	20	21	51
Chaffins (Unionville)	980	<10	41	<10	<10	11	51
Chaffins (Wachusett)	440	<10	37	10*	20	15	50
Cook Brook (Wyoming)	1440	<10	102	40	**70**	35	51
East Wachusett (140)	2500	<10	78	10	25	17	51
East Wachusett (31)	1000	<10	38	<10	<10	10	51
East Wachusett (Bull)	1040	<10	45	10	10	12	51
French Brook (70)	180	<10	24	<10*	10	11	55
Gates Brook (1)	890	<10	73	20	20	27	54
Gates Brook (2)	>2000	<10	170	40	60	44	55
Gates Brook (3)	910	<10	94	45	20*	39	54
Gates Brook (4)	950	<10	129	50	40	49	55
Gates Brook (6)	>2000	<10	208	40	70	40	55
Gates Brook (9)	810	<10	106	20	30	32	55
Hastings Cove Brook	190	<10	19	<10	10	<10	52
Hog Hill Brook	890	<10	52	10*	10*	14	49
Houghton Brook	850	<10	90	20	15	26	51
Jordan Farm Brook	>2000	<10	122	10	10	19	50
Justice Brook	4900	<10	107	<10	<10	<10	51

*below historic levels

TABLE 3 (part two of two)

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN (2006)	MEDIAN (2005)	GEO MEAN	SAMPLES
Keyes (Gleason)	1400	<10	51	10	<10*	14	51
Keyes (Hobbs)	870	<10	31	10	10	11	51
Keyes (Onion)	1870	<10	95	10	<10	20	51
Malagasco Brook	1670	<10	103	25	20	29	54
Malden Brook	640	<10	59	20	10*	20	55
Muddy Brook	240	<10	32	<10*	10	13	55
Oakdale Brook	>2000	<10	160	20*	40	31	51
Quinapoxet River (CMills)	790	<10	49	20*	30*	13	105
Quinapoxet River (dam)	540	<10	53	10*	20	17	51
Quinapoxet River (Mill St)	70	<10	16	10	10	10	51
Rocky Brook	1550	<10	68	20	15	20	51
Rocky (E Branch)	50	<10	<10	<10	<10	<10	44
Scanlon Brook	1340	<10	101	10	<10	21	51
Scarlett Brook	>2000	<10	142	30	30	33	51
Scarlett (Rt12)	7000	<10	301	40	30	49	49
Stillwater (62)	1720	<10	116	20	30	28	51
Stillwater River (SB)	2900	<10	86	20	30	18	105
Swamp 15 Brook	>2000	<10	181	20	30	26	51
Trout Brook	280	<10	24	10	10	12	51
Warren Tannery Brook	940	<10	84	10*	10*	21	50
Waushacum (Conn)	680	<10	70	15	20	22	44
Waushacum (filter)	680	<10	68	10	10	19	35
Waushacum (Fairbanks)	700	<10	65	20	20	22	51
Waushacum (Pr)	570	<10	49	20	20	23	51
Waushacum (WWP)	70	<10	11	<10	<10	<10	51
West Boylston Brook	1950	<10	139	70	60	55	54
Wilder Brook	2700	<10	248	20	30	34	35

*below historic levels

Arithmetic mean fecal coliform concentrations have been part of the Massachusetts Class A surface water quality standards for some time, but there are limitations with this parameter as described earlier and the Massachusetts Department of Environmental Protection switched to a new standard in 2007. Annual median has been used as an alternative metric by DCR staff for many years as a better way to represent overall water quality. Nearly all of the annual median concentrations recorded in 2006 were similar to those measured during 2005 (Table 3). Nine tributary stations (Chaffins at Malden, Chaffins at Wachusett, French, Hog Hill, Muddy, Oakdale, Warren Tannery, and the Quinapoxet River at Canada Mills and at the dam) recorded historic low annual medians. A few stations showed a decline in water quality with rising annual median values, but they were the exception. All three stations on Beaman Pond Brook had elevated annual medians, but values recorded were similar to medians seen in 2004 and well within historical limits. Minor declines in water quality at two stations on Gates Brook and at stations on Scarlett and Malagasco Brooks also do not appear significant. Although the annual median at West Boylston Brook only increased by a small amount as well, it was the third year in a row that this metric had increased and the annual median in 2006 was the highest in more than ten years. This is a disturbing trend that will be investigated in detail during 2007. Annual median in Asnebumskit Brook (Princeton Street) was dramatically higher than in previous years and was indicative of a serious problem. This site was studied in detail during the summer of 2006 and some conclusions drawn, but further investigations are necessary.

The highest annual median concentration was from Asnebumskit Brook (Princeton Street). Beaman Pond Brook (3½) had the second highest, but it was less than half the value recorded from Asnebumskit Brook. Beaman Pond Brook (3) recorded the third highest annual median. West Boylston Brook, Beaman Pond Brook (2), Cook Brook, Scarlett (Rt. 12), and four stations on Gates Brook rounded out the top eleven. When geometric mean values are used to rank the tributary stations there is no change in the composition of the top (worst) eleven and the order of the top three remains the same.

The annual median fecal coliform value for all fifty-four sampling stations was 20 cfu/100mL in 2004 and 2005 and improved to 10 cfu/100mL in 2006. Other metrics showed a similar trend of overall watershed improvement. The percentage of tributary samples that exceeded the previous Class A standard of 20 cfu/100mL dropped slightly from 43% to 41%; the percentage of samples containing more than 100 cfu/100mL dropped from 18% to 16%.

Annual mean and annual median values were strongly impacted by rainfall events as illustrated in Tables 4 and 5 on the following page. Annual statistics were examined from 2006 as well as from the previous two years. Fecal coliform samples collected during or within twenty-four hours of a significant (>0.2”) rain event (storm samples) had an annual mean more than twice the overall mean and more than four times the mean of samples collected only during or following a period of dry weather (dry samples). Samples collected between twenty-four and forty-eight hours of a storm were much less impacted, but still reflected some negative effects in most cases.

Annual median values reflect a similar pattern, although the impacts from storms appear to be of less significance simply due to the fact that annual median is not greatly impacted by occasional high values.

TABLE 4

MEAN FECAL COLIFORM – EFFECT OF >0.2" RAINFALL
(colonies/100 mL)

YEAR	**MEAN** all samples	**MEAN** dry samples	**MEAN** storm samples	**MEAN** post storm (48hrs) samples
2004	103	57	302	96
2005	178	61	524	60
2006	106	60	266	79

TABLE 5

MEDIAN FECAL COLIFORM – EFFECT OF >0.2" RAINFALL
(colonies/100 mL)

YEAR	**MEDIAN** all samples	**MEDIAN** dry samples	**MEDIAN** storm samples	**MEDIAN** post storm (48hrs) samples
2004	20	10	70	20
2005	20	10	60	20
2006	10	10	60	30

The impact of storm events on water quality can also be seen by examining the percentage of samples that exceed the previous Class A standard of 20 cfu/100mL (Table 6) or the percentage of samples that exceed 100 cfu/100mL (high concentrations referred to as "spikes") (Table 7).

TABLE 6

ELEVATED FECAL COLIFORM – EFFECT OF >0.2" RAINFALL
(>20cfu/100 mL)

YEAR	**% > 20cfu** all samples	**% > 20cfu** dry samples	**% > 20cfu** storm samples	**% > 20cfu** 48 hrs post storm
2004	42	35	71	47
2005	43	34	63	47
2006	41	30	68	52

TABLE 7

FECAL COLIFORM SPIKES – EFFECT OF >0.2" RAINFALL (>100cfu/100 mL)

YEAR	% > 100cfu all samples	% > 100cfu dry samples	% > 100cfu storm samples	% > 100cfu 48 hrs post storm
2004	18	11	43	24
2005	17	10	37	14
2006	16	9	36	16

Not every station on every tributary is impacted equally by rain events. Some of the sampling locations show a significant decline in water quality, with annual median values of wet weather samples as much as fifty times higher than annual median values of the dry weather samples. The percentage of wet weather samples exceeding Class A standards of 20 cfu/100mL and 100 cfu/100mL also is much higher at many stations. Examples of stations that are storm-influenced are included below in Table 8.

TABLE 8

STORM-INFLUENCED SAMPLING STATIONS

STATION	MEDIAN (dry)	MEDIAN (wet)	%>20 (dry)	%>20 (wet)	%>100 (dry)	%>100 (wet)
Asnebumskit (Mill)	10	205	26	90	9	60
Beaman 3	35	445	54	67	42	67
Beaman 3.5	80	610	56	86	44	86
Cook Brook	20	255	46	100	11	100
Gates Brook (2)	30	160	59	77	9	54
Gates Brook (3)	30	190	55	77	6	54
Gates Brook (4)	30	200	53	85	24	62
Gates Brook (6)	20	120	47	92	21	69
Gates Brook (9)	10	180	32	77	24	54
Jordan Farm Brook	5	290	22	86	5	71
Malagasco	10	130	32	79	3	57
Quinapoxet (dam)	7	110	21	70	3	50
Swamp15	10	515	29	90	3	80
Warren Tannery	10	115	21	90	9	50
West Boylston	30	180	61	92	15	76

Some stations show very little or no difference between dry and wet weather water quality, and in some instances actually have better water quality during or immediately after storms. Most of these stations have very good water quality throughout the year and are in relatively pristine areas with few potential sources of contamination. Some are buffered by upstream physical features such as ponds or wetlands. One of the stations (Asnebumskit Brook at Princeton Street) has extremely poor water quality during much of the year and does not show impacts from storm events, suggesting that the source is continuous and significant. Examples of stations that are not influence by storm events are shown in Table 9.

TABLE 9

SAMPLING STATIONS NOT STRONGLY INFLUENCED BY STORM EVENTS

STATION	MEDIAN (dry)	MEDIAN (wet)	%>20 (dry)	%>20 (wet)	%>100 (dry)	%>100 (wet)
Asnebumskit (Princeton)	280	455	85	80	65	70
Ball	7	15	24	48	0	8
Houghton	10	30	42	62	14	23
Justice	5	10	8	23	0	8
Keyes (Onion)	7	10	31	46	19	23
Rocky (E Branch)	5	5	6	0	0	0
Waushacum (Fairbanks)	20	40	38	50	19	25
Waushacum (filterbeds)	10	20	27	40	19	0
Waushacum (WWP)	5	5	11	12	0	0

It was mentioned earlier that rain within forty-eight hours has an overall negative impact on water quality, although generally to a lesser extent than more recent storm events. A matrix was developed for each sampling station that illustrates the relationship between rain events, the timing of these events, and fecal coliform concentrations. These are included with weekly tributary data in the appendix, and a sample is presented below. It appears that sampling stations respond in different ways to storm events, with smaller streams in urban settings seeing more immediate impacts than do larger rivers. This will be addressed in more detail next year in a separate report covering the previous ten years (1998 – 2007) of water quality data.

fecal coliform concentration (cfu/100mL)	0-20	21-99	100+
dry (no rainfall w/i 48 hours)	21	10	0
0.2 + ” rain w/i 6 hours	0	2	5
0.2 + ” rain w/i 6 and w/i 24 hours	1	0	2
0.2 + ” rain w/i 24 hours	0	3	3
0.2 + ” rain w/i 24 and w/i 48 hours	0	0	1
0.2 + ” rain w/i 48 hours	2	1	0

Mean and median values appeared to be strongly impacted by season as well as by rainfall events. Statistics were examined from 2006 and from the previous two years, and are shown in below in Tables 10 and 11. In all three years, both mean and median values were lowest during the winter months (January-March), increased in the spring (April-June), were highest during the summer (July-September), and then dropped in the fall (October-December). Fall mean and median values were less than spring values in 2004, but did not drop as much in 2005 or 2006.

TABLE 10

MEAN FECAL COLIFORM – SEASONAL EFFECT
(colonies/100 mL)

YEAR	MEAN winter	MEAN spring	MEAN summer	MEAN fall
2004	20	100	256	40
2005	41	89	429	178
2006	26	100	186	121

TABLE 11

MEDIAN FECAL COLIFORM – SEASONAL EFFECT
(colonies/100 mL)

YEAR	MEDIAN winter	MEDIAN spring	MEDIAN summer	MEDIAN fall
2004	5	30	60	10
2005	5	20	60	20
2006	5	20	55	25

The impact of season on water quality as reflected by the percentage of samples that exceed the previous Class A standard of 20 cfu/100mL (Table 12) or the percentage of samples that exceed 100 cfu/100mL (Table 13) was nearly identical, with lowest values in the winter and highest in the summer. Summer values seem to be improving; winter values are very consistent.

TABLE 12

FECAL COLIFORM %>20cfu – SEASONAL EFFECT
(colonies/100 mL)

YEAR	% > 20cfu winter	% > 20cfu spring	% > 20cfu summer	% > 20cfu fall
2004	13	57	74	25
2005	15	44	71	42
2006	13	48	65	37

TABLE 13

FECAL COLIFORM %>100cfu – SEASONAL EFFECT
(colonies/100 mL)

YEAR	% > 100cfu winter	% > 100cfu spring	% > 100cfu summer	% > 100cfu fall
2004	2	24	39	7
2005	5	15	33	16
2006	3	19	27	16

Seasonal variation and storm event impacts were examined together to see how the two combine to effect water quality. The overall response was not surprising, with patterns very similar to those shown in the preceding tables and weather being of much greater significance than season. Regardless of the metric used, water quality appears best during dry winter weather conditions. Wet winter weather appeared to have the second best water quality in most cases, but wet winter samples were limited in number since there are usually few rain events at that time of year. All dry weather samples, regardless of the seasonal grouping, were of better water quality than the remaining three seasons of wet weather samples (Table 14). These are general patterns and have been noted consistently for the past several years, but are not necessarily true for all stations on all tributaries in the watershed. An in-depth examination of both seasonal and weather related impacts on individual tributaries will be included in the ten-year summary report scheduled to be published during 2008.

TABLE 14

FECAL COLIFORM – SEASONAL PATTERNS (DRY AND WET) IN 2006

	WINTER	SPRING	SUMMER	FALL
MEAN – DRY	16*	65	119	57
MEAN – WET	73	177	390	392
MEDIAN – DRY	5*	10	30	10
MEDIAN – WET	10	50	120	80
%>20 – DRY	11*	36	56	25
%>20 – WET	27	67	85	73
%>100 – DRY	2*	13	17	9
%>100 – WET	7	32	52	42

*best of metric

Multiple sampling stations on Gates Brook have been utilized for many years to try and locate sources of fecal contamination. Gates Brook was historically one of the most contaminated tributaries in the watershed, although water quality has improved as an increasing number of homes are connected to the new municipal sewers. A total of 1474 homes and businesses have been connected to the West Boylston sewer system in the past nine years, 610 within the Gates Brook subbasin. Although more than seventy-four percent of all homes in the Gates Brook subbasin are now connected, water quality in Gates Brook is still poor during both wet and dry weather. Specific sources of contamination remain largely undetected and no clear patterns have emerged. In some years the stations near the headwaters have been more contaminated than stations close to the reservoir, while in other years the highest fecal coliform concentrations were noted in the middle stretches of the tributary. Gates 4 had the worst water quality during 2006 as measured by most metrics (see Table 15), with Gates 2 containing the highest percentage of samples that exceeded 20 colonies per 100mL. These two stations were also the most impacted during 2005. The station closest to the reservoir (Gates 1) once again had the best water quality, although water quality at the headwater station (Gates 9) has improved to nearly the same level.

TABLE 15

FECAL COLIFORM – GATES BROOK STATIONS
(colonies/100 mL)

STATION	MEAN	MEDIAN	GEOMEAN	%>20	%>100
Gates 1	73	20	27	46	15
Gates 2	170	40	44	67	20
Gates 3	94	45	39	62	20
Gates 4	129	50	49	64	33
Gates 6	208	40	40	60	33
Gates 9	106	20	32	45	29

Samples were collected from three stations on Beaman Pond Brook to continue an investigation of water quality problems discovered several years ago during Environmental Quality Assessment fieldwork. Water samples were collected during dry and wet conditions. Data were collected from Station #2 (downstream of houses), Station #3 (downstream of pond), and Station #3½ (upstream of pond) and are summarized in Table 16. It is clear from the 2006 results that water quality was poorest overall at the upstream station. This was also the case for wet weather samples.

TABLE 16

FECAL COLIFORM – BEAMAN POND BROOK STATIONS
(colonies/100 mL)

STATION	MEAN	MEDIAN	GEOMEAN	%>20	%>100
Beaman Pond #2	162	50	38	62	23
Beaman Pond #3	336	80	57	57	43
Beaman Pond #3½	411	130	86	62	51

Data from 2004 showed the worst water quality at Station #3½, with annual median fecal coliform concentration of 175 cfu/100mL (Table 17). Horses were being stabled on site during 2004 and there were no best management practices being used by the owners to keep manure out of the brook. Data from 2005 showed dramatic water quality improvements as a result of the removal of the horses from the site. Horses returned to the site in 2006, but a number of best management practices were instituted to reduce bacterial contamination. Unfortunately water quality at all three stations showed an obvious decline from the previous year. It was determined, however, that the contamination was likely from an alternative source, possibly from intermittent sewerage releases at a neighboring property. Investigations will continue during 2007.

TABLE 17

FECAL COLIFORM METRICS – BEAMAN POND BROOK STATIONS
(colonies/100 mL)

STATION	**2004med**	**2005med**	**2006med**	**2004%>100**	**2005%>100**	**2006%>100**
Beaman Pond #2	90	30	50	47	16	23
Beaman Pond #3	70	30	80	40	28	43
Beaman Pond #3½	175	40	130	58	27	51

Fecal coliform samples have been collected from stations on Cook Brook for the past nine years to evaluate the impacts of sewering on water quality. Cook Brook flows through the Pinecroft neighborhood of West Boylston and Holden, an area known for numerous problems with outdated or inadequate septic systems. A decision was made in the late 1990s to replace the septic systems with a municipal sewer system. Fecal coliform data were collected in 1998 prior to sewer construction, and weekly data collection has continued since then. Nearly seventy-five percent of the homes have been connected to sewers in this neighborhood, and water quality initially appeared to improve, with lower annual medians and fewer samples exceeding 100 colonies per 100mL. A closer look at the data revealed that this was true for dry weather samples, and for overall data, but that for wet weather samples there was actually little improvement. This suggested that a source of fecal coliform remained that only reached the tributary during storm events. One possible source of contamination is the large number of dogs that live in the neighborhood. Work is underway to promote waste control and hopefully positive water quality changes will occur. Field work will continue during 2007 to determine if other sources can be located.

Samples from Scarlett Brook and West Boylston Brook do not show any dramatic positive change in water quality. Both tributaries have contributory subbasins that are now serviced by a municipal sewage system, and it was hoped that water quality would improve. Fecal coliform concentrations have generally remained unchanged, although in West Boylston Brook they have actually increased slightly. It is not clear why this has occurred. Not all homes are connected to the sewer, and it may be that the first wave of hookups are reducing total groundwater inputs and therefore reducing flow in the brooks, concentrating existing contaminants. Mandatory connections will help increase the number of hookups and hopefully lead to water quality improvements in the future.

Samples collected from Asnebumskit Brook at Princeton Street historically have had elevated fecal coliform counts beginning in May or June and lasting throughout the summer and much of the fall. Samples were collected at a number of upstream locations in September of 2005, but fecal coliform counts were elevated at all sites and no source was identified. A number of possibilities were considered including roosting pigeons, dogs, wildlife, and inadequate septic systems. There was a dramatic decline in most water quality metrics calculated for samples collected during 2006, and elevated fecal coliform concentrations were recorded from March through early November. Additional sampling was done in both wet and dry weather, but the only conclusions drawn were that maximum concentrations were higher than usual and the declining water quality was not directly connected to rain events. Wet weather samples were usually of poorer quality than dry weather samples, wet weather water quality remained constant during the three years while dry weather water quality declined significantly (Table 18). It has recently been theorized that sediments in the brook may contain a viable population of fecal coliform that might become more significant during periods of lower flow. Staff will continue to investigate and attempt to determine the source of the problem.

TABLE 18

FECAL COLIFORM – ASNEBUMSKIT BROOK (Princeton Street)
(colonies/100 mL)

YEAR	MEDIAN	%>20 dry	%>20 wet	%>100 dry	%>100 wet
2004	80	76	78	47	67
2005	60	53	77	44	69
2006	360	85	80	65	70

Water quality in the Wachusett watershed tributaries has historically been unable to meet state standards due to the negative impact of a single or few high samples. New standards recently adopted by the DEP will provide a more rational means of looking at current and past water quality data, and consequently should be easier to meet. Drinking water tributaries (including all streams in the Wachusett watershed) will be required to maintain a geometric mean of less than 206 *E. coli* per 100mL. Assuming that 100% of fecal coliform are *E. coli* (worst case), the standard would be met at all but one of the fifty-four sampling stations during 2006 and at all other stations in 2005 and 2004 (Table 19).

Twenty-seven (fifty percent) of the stations had a geometric mean of no more than twenty fecal coliform per 100mL in 2006, and over the past three years more than forty-five percent of the stations had an annual geometric mean of no more than twenty. Geometric mean is a measure of central tendency, like median values, and is a much more reasonable metric than arithmetic mean when discussing non-linear data. The geometric mean is especially useful when you have data which include extreme outliers, like fecal coliform concentrations in tributaries. Use of the geometric mean for future assessments will allow reasonable comparisons between current and historic data and will be used as part of the detailed assessment which will review water quality data from 1998-2007 and compare it with data from the previous ten-year period.

TABLE 19 (part one of two)

GEOMETRIC MEAN FECAL COLIFORM

STATION	2006	2005	2004
Asnebumskit (Mill)	25	30	27
Asnebumskit (Prin)	**228**	76	87
Ball Brook	13	12	15
Beaman 2	38	30	66
Beaman 3	57	47	69
Beaman 3.5	86	42	134
Boylston Brook	17	19	30
Chaffins (Malden)	19	24	22
Chaffins (Poor Farm)	21	30	23
Chaffins (Unionville)	11	12	10
Chaffins (Wachusett)	15	30	26
Cook Brook (Wyoming)	35	74	36
East Wachusett (140)	17	22	19
East Wachusett (31)	10	10	11
East Wachusett (Bull)	12	12	13
French Brook (70)	11	14	17
Gates Brook (1)	27	23	26
Gates Brook (2)	44	54	29
Gates Brook (3)	39	30	32
Gates Brook (4)	49	45	40
Gates Brook (6)	40	58	49
Gates Brook (9)	32	28	42
Hastings Cove Brook	<10	14	12
Hog Hill Brook	14	19	14
Houghton Brook	26	24	18
Jordan Farm Brook	19	39	16
Justice Brook	<10	<10	<10

TABLE 19 (part two of two)

GEOMETRIC MEAN FECAL COLIFORM

STATION	2006	2005	2004
Keyes (Gleason)	14	<10	13
Keyes (Hobbs)	11	15	18
Keyes (Onion)	20	<10	<10
Malagasco Brook	29	26	26
Malden Brook	20	17	30
Muddy Brook	13	17	20
Oakdale Brook	31	38	49
Quinapoxet River (CMills)	13	30	40
Quinapoxet River (dam)	17	24	19
Quinapoxet River (Mill St)	10	12	11
Rocky Brook	20	19	12
Rocky (E Branch)	<10	10	<10
Scanlon Brook	21	15	13
Scarlett Brook	33	40	26
Scarlett (Rt12)	49	44	20
Stillwater (62)	28	26	25
Stillwater River (SB)	18	27	34
Swamp 15 Brook	26	28	26
Trout Brook	12	15	10
Warren Tannery Brook	21	19	19
Waushacum (Conn)	22	23	12
Waushacum (filter)	19	33	23
Waushacum (Fairbanks)	22	30	25
Waushacum (Pr)	23	23	14
Waushacum (WWP)	<10	11	<10
West Boylston Brook	55	63	47
Wilder Brook	34	37	36

3.2 NUTRIENTS

Samples for alkalinity, conductivity, nitrate-nitrogen, nitrite-nitrogen, ammonia, total phosphorus, total silica, dissolved silica, total suspended solids, UV-254, and total organic carbon were collected in April, May, June, July, October, and December from nine tributary stations and analyzed at the MWRA Deer Island Lab using methods with low detection limits. Monthly samples for the same parameters plus a range of metals were collected (except during November) from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Samples for nitrate-nitrogen, nitrite-nitrogen, and ammonia were filtered in the field using a 1 micron glass fiber Acrodisc filter and then frozen. Samples for total phosphorus were frozen without filtration. Samples for the other parameters were preserved as necessary according to standard methods. Flow measurements at these stations were determined each week using staff gages and USGS rating curves, or taken directly from continuous USGS recording devices (Stillwater and Quinapoxet River). All data are included in an appendix to this report and are discussed in the following section.

Nitrate-nitrogen concentrations measured in the eight routine tributaries ranged from 0.011 mg/L NO_3-N to 2.86 mg/L NO_3-N (Table 20). Nitrate levels are usually highest in Gates and West Boylston Brooks and remain significantly elevated with respect to the other tributaries and the reservoir. This was again true in 2006. Both of these brooks flow through highly developed neighborhoods. Elevated nitrate levels in Gates and West Boylston Brooks are likely due to the high number of improperly functioning septic systems and the density of residential and commercial development in these subbasins.

TABLE 20

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.218	0.898	0.164	2.27	2.86	0.608	0.440	0.311
MIN	0.011	0.440	0.055	0.965	1.43	0.035	0.215	0.041
MEAN	0.067	0.687	0.100	1.39	2.21	0.356	0.309	0.159

Samples were collected as part of an ongoing study to evaluate the impacts of sewering on water quality in a small urbanized tributary (Cook Brook). Concentrations are usually higher in Cook Brook than in any of the routine tributaries sampled during the year (including Gates and West Boylston Brooks), and this was true again in 2006. Many of the homes in the Cook Brook subbasin have now been connected to the sewer, and improvements to water quality should begin to occur soon. Samples were also collected from two similar sized subbasins with different land uses for comparison purposes. Concentrations in Jordan Farm Brook (agriculture) and in Rocky Brook (undeveloped) remain significantly lower than in Cook Brook (dense residential) although the maximum value from Jordan Farm Brook was considerably higher than expected (Table 21).

TABLE 21

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

STATION	COOK	COOK	COOK	COOK	COOK	COOK	COOK	Jordan Farm	Rocky (EBranch)
YEAR	2000	2001	2002	2003	2004	2005	2006	2006	2006
MAX	5.82	4.59	4.63	4.78	4.46	3.15	3.26	2.97	0.020
MIN	2.18	1.98	4.39	1.90	1.71	2.34	2.35	0.63	<0.005

Nitrite-nitrogen was rarely detected and then at very low concentrations, with a maximum recorded value of 0.008 mg/L. Only four of seventy-six samples (West Boylston Brook in April, Malagasco Brook in June, Muddy Brook in July, and Malden Brook in December) contained detectable concentrations of nitrite-nitrogen (>0.005 mg/L) during 2006.

Ammonia was detected in all tributaries during the year with most concentrations similar to those seen in the previous three years. The highest concentrations were recorded in samples collected from French and Muddy Brooks (Table 22). Data were collected six times during the year at most stations (eleven times from the Quinapoxet and Stillwater Rivers) to get a better overall picture of seasonal changes and to allow for the calculation of meaningful annual statistics.

TABLE 22

AMMONIA-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAG	MUDDY	GATES	W.BOYL	MALDEN	QUIN	STILL	COOK	J.FARM	ROCKY (EB)
MAX	0.140	0.036	0.137	0.017	0.025	0.027	0.024	0.073	0.008	0.008	0.007
MIN	0.019	0.007	0.029	<0.005	0.008	0.008	0.005	0.007	<0.005	<0.005	<0.005
MEAN	0.057	0.019	0.075	0.006	0.016	0.018	0.013	0.023	<0.005	<0.005	<0.005

Phosphorus is an important nutrient, and is the limiting factor controlling algal productivity in Wachusett Reservoir. EPA Water Quality Criteria recommend a concentration of no more than 0.05 mg/L total phosphorus in tributary streams in order to prevent accelerated eutrophication of receiving water bodies. Concentrations measured in the eight routine Wachusett tributaries during 2006 ranged from <0.005 mg/L to 0.134 mg/L total P (Table 23). Mean concentrations were lower in all of the smaller tributaries than they were in 2005, but concentrations in the two large rivers were actually slightly higher. Only four of seventy-six samples collected in 2006 exceeded the recommended maximum concentration, two from the Stillwater River and one each from the Quinapoxet River and French Brook.

TABLE 23

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.062	0.047	0.024	0.039	0.035	0.041	0.079	0.134
MIN	0.017	<0.005	<0.005	<0.005	<0.005	0.006	<0.005	0.007
MEAN	0.036	0.025	0.014	0.019	0.018	0.023	0.025	0.032

Data from Cook Brook in the Pinecroft neighborhood (Table 24) appear to show improving water quality. Total phosphorus data collected in 1998 prior to sewer construction included a maximum value of 4.74 mg/L. Maximum values have not exceeded 0.2 mg/L since that time, and declined annually through 2003. The maximum value recorded in 2004 was twice as high as 2003, however, and the maximum was even higher in 2005, but the maximum in 2006 was the lowest ever. Annual median values have been very consistent during the past seven years with the exception of 2004 when the annual median was twice that of all other years, and this year with an all-time low annual median. A complete analysis of nutrient data including an assessment of the impacts of storm events is underway and will be included in the ten-year summary of water quality data to be published within the next few years.

Total phosphorus samples were also collected from two similar sized subbasins with different land uses for comparison purposes. Concentrations in Rocky Brook (undeveloped) remain lower than in Cook Brook (dense residential), but concentrations in Jordan Farm Brook (agriculture) were actually higher than in the other two for the first time.

TABLE 24

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

STATION	COOK	COOK	COOK	COOK	COOK	COOK	COOK	Jordan Farm	Rocky (EBranch)
YEAR	2000	2001	2002	2003	2004	2005	2006	2006	2006
MAX	0.095	0.053	0.031	0.033	0.081	0.101	0.016	0.032	0.009
MIN	0.008	0.012	0.021	0.009	0.031	0.016	<0.005	<0.005	<0.005
MEDIAN	0.020	0.024	0.026	0.021	0.056	0.024	0.012	0.016	0.007
SAMPLES	11	10	2	2	2	5	6	6	6

Silica concentrations ranged from a low of 2.18 mg/L in April (French Brook) to a high of 12.60 mg/L in October (West Boylston Brook). The annual mean concentration in the watershed during 2006 was 8.07 mg/L, slightly higher than the annual mean recorded during the previous four years. The annual mean concentration was highest in Cook Brook; the lowest annual mean concentrations were in French Brook and the Quinapoxet River (Table 25).

TABLE 25

SILICA CONCENTRATIONS (mg/L)

station	FRENCH	MALAG	MUDDY	GATES	W.BOYL	MALDEN	QUIN	STILL	COOK	J.FARM	ROCKY (EB)
MAX	8.41	11.70	9.41	10.60	12.60	11.00	7.34	8.75	10.80	10.40	10.80
MIN	2.18	5.18	6.13	6.93	7.33	7.56	4.19	4.86	8.72	7.38	6.75
MEAN	5.51	8.74	7.67	9.22	9.35	9.30	5.86	7.09	10.06	9.06	8.73

Dissolved silica was also measured during 2006. Concentrations were very similar to total silica results, although in almost all instances were slightly lower. Dissolved silica is an important component of the plankton growth cycle and is utilized by both diatoms and flagellated golden-brown algae.

Total suspended solids are those particles suspended in a water sample retained by a filter of 2μm pore size. These particles can be naturally occurring or might be the result of human activities. Total suspended solids in Wachusett tributaries ranged from <5.0 mg/L to 8.5 mg/L, with seventy-one of seventy-six samples containing less than the detection limit. Suspended solids were detected in Malden Brook during April, in the Quinapoxet River in May, in French Brook in June, in the Stillwater River in July, and in West Boylston Brook in October. Total suspended solids are not considered a parameter of concern at this time due to the very low concentrations.

Total organic carbon (TOC) and UV-254 measure organic constituents in water, and are a useful way to predict precursors of harmful disinfection byproducts, although this is of less significance in the Wachusett watershed now that primary disinfection is accomplished using ozone instead of chlorine. TOC in the tributaries ranged from 1.28 to 15.1 mg/L, with an overall mean value of 4.10 mg/L. These values are similar to measurements done during the past three years. The highest readings were again recorded from Malagasco Brook and French Brook, and the lowest from Gates Brook and West Boylston Brook. Measurements of UV-254 were comparable to TOC measurements as expected. Organic compounds such as tannins and humic substances absorb UV radiation and there is a correlation between UV absorption and organic carbon content. The highest UV-254 readings were also from Malagasco and French Brooks, and the lowest were from Gates Brook and West Boylston Brook.

Concentrations of twenty-one metals were measured in monthly samples collected from the Stillwater and Quinapoxet Rivers. No antimony, beryllium, cadmium, nickel, or selenium were detected in any samples, while arsenic, chromium, copper, lead, mercury, silver, and zinc were present but at very low concentrations (less than 10 μg/L). Barium and thallium were present in slightly higher concentrations but never higher than 23 μg/L. Aluminum, calcium, iron, magnesium, manganese, potassium, and sodium were present at higher concentrations (Table 26) comparable to values recorded during the past three years. A number of these metals that are never detected or rarely detected will not be monitored in 2007.

TABLE 26

METALS CONCENTRATIONS (mg/L) – annual mean and range

station	Al	Ca	Fe	Mg	Mn	K	Na
QUINAPOXET	0.10	7.22	0.32	1.36	0.06	1.48	21.9
range	0.25 - ND	9.34 - 5.31	0.89 - 0.13	1.74 - 1.05	0.22 – 0.04	1.92 - 1.24	29.2 – 17.1
STILLWATER	0.11	6.76	0.45	1.22	0.08	1.54	20.0
range	0.29 - 0.03	14.2 - 3.75	0.84 - 0.04	2.68 - 0.72	0.15 - 0.02	2.93 - 0.91	37.7 - 12.9

3.3 SPECIFIC CONDUCTANCE

Fresh water systems contain small to moderate amounts of mineral salts in solution. Specific conductance is a measure of the ability of water to carry an electric current, dependent on the concentration and availability of these ions. Elevated conductivity levels indicate contamination from stormwater or failing septic systems, or can be the result of watershed soil types.

Specific conductance was measured weekly at all stations with a low of 33 µmhos/cm recorded in March at Justice Brook and at Keyes Brook (Gleason) and a high of 1761 µmhos/cm noted in January at Gates Brook (Pierce Street), likely related to application of road salt. Annual median ranged from 46 µmhos/cm (Justice Brook) to 907 µmhos/cm (Gates Brook at Pierce Street). Annual values in most tributaries were slightly lower than the previous year, with no tributaries recording their highest annual median. Three of six stations on Gates Brook actually recorded their lowest annual medians since 2000/2001.

Criteria proposed in the mid 1990s related specific conductance and fecal coliform levels to the likelihood of contamination from failing septic systems. A simple statistical analysis was used to develop a ranking system for tributaries, using percent exceedence of specific criteria. Tributaries with more than fifty percent of samples exceeding the Class A Standard for fecal coliform of twenty colonies per 100mL are potentially impacted by septic systems. Impacts are considered minor if less than eighty percent of samples exceed a specific conductance of 120 µmhos/cm, moderate if more than eighty percent of samples exceed 120 µmhos/cm, and severe if more than twenty percent of samples exceed 360 µmhos/cm. These criteria appeared to give a fairly good indication of whether a sampling location was impacted by failing septic systems or an alternative source of contamination, although annual flow should be considered as well. Changes in sampling equipment have led to overall increases in specific conductance in the watershed and these criteria should be updated or dropped. The use of fifty percent exceedence as an indicator of potential impact by septic systems should also be used with caution, since rain events and periods of reduced flow have a significant impact on fecal coliform concentrations and sample timing during the year could easily change overall results. Conductivity appears to be directly related to stream flow, with “dry” years (low flows) elevating mean annual conductivity. Years with less precipitation and lower flow result in higher overall conductivity measurements and appear to increase the number of streams severely impacted. For this reason multiple years should be used in assessing these criteria.

An assessment of specific conductance and fecal coliform data from 2006 using the criteria described above suggests that only twelve of fifty-four stations (22%) were likely contaminated by improperly functioning septic systems. All three stations on Beaman Pond Brook, four of six stations on Gates Brook, and stations on Cook, Scarlet, and West Boylston Brooks were considered severely impaired. Problems on Cook, Gates, Scarlett, and West Boylston Brooks have been well documented, and sewers were constructed specifically to deal with this issue. Beaman Pond Brook has had problems believed to be related to horses rather than septic systems, although additional investigative work seems to suggest that septic system problems or sewer overflows may be the source of contamination.

Asnebumskit Brook at Princeton Street and Scarlett Brook at Route 12 showed moderate impacts from septic systems as they did in 2005. These two tributaries have exhibited poor water quality in the past although the source remains undetermined.

A multi-year examination (1998 through 2006) of this assessment showed conditions initially improving and then stabilizing in the watershed. Nearly fifty percent of the stations assessed in 1998 were deemed likely contaminated by faulty septic systems. This declined to thirty-eight percent in 1999, thirty-three percent in 2000, and thirty percent in 2001 and in 2002. Poor conditions in 2003, with more than fifty percent of the stations likely contaminated by septic systems, were due to the addition of several problem stations to the routine weekly sampling run and the dropping of two locations with good water quality. A large number of tributaries were assessed in 2004, 2005, and 2006 to provide a better overall picture of water quality in the watershed, and the percentage of stations likely contaminated by septic systems declined each year to a historic low in 2006 of only twenty-two percent.

3.4 TURBIDITY

Weekly samples were collected from all tributary stations beginning in March. Measurements ranged from 0.15 to 34 NTU, with a watershed mean of 1.4 NTU. Lowest readings were from Rocky Brook (East Branch) and Cook Brook; the highest were from Jordan Farm Brook, Scarlett Brook, and Beaman Brook. Storm events had an obvious impact on turbidity, with a watershed mean of 2.3 NTU for storm samples and a watershed mean of 1.1 NTU for 'dry' samples. Not all high measurements were due to storm events; four samples with turbidity above 10 NTU (including the highest of the year from Jordan Farm Brook) were collected during dry weather.

Five tributaries had elevated turbidity throughout the year and regardless of weather conditions. The aptly named Muddy Brook had the highest annual mean (5.1 NTU) and the highest dry weather mean (4.7 NTU). Fine particulate matter is likely entering the stream at the power line right-of-way. Erosion is accelerated by ATV use in the area. Elevated turbidity in Muddy Brook is the probable cause of impacts to macroinvertebrate populations, unexplained until this time.

Waushacum Brook, Warren Tannery Brook, Gates Brook, and French Brook all had elevated turbidity as well, although annual mean was only half that seen in Muddy Brook. Most high values were apparently unrelated to storm events, with dry means nearly as high as annual mean. One exception was Warren Tannery Brook, where an obvious impact from storm events was noted. Warren Tannery Brook continues to be affected by the large construction project at the Wachusett Regional High School, with very turbid water entering the brook during most storms.

3.5 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity, or the measure of a solution's acidity or alkalinity, is expressed as pH on a scale ranging from 0 to 14. Underlying geologic formations, biological processes, and human contaminants impact the pH of a water body. In this region most streams and lakes tend to be relatively acidic (pH less than 7) due to granite bedrock and the impact of acid precipitation originating from the Midwest.

No measurements of pH have been done in the tributaries for a number of years. More than a decade of routine sampling in the tributaries had shown very little variation either seasonally or over time. Historic low values in some tributaries may have been caused by impacts of runoff from acid precipitation, while all other recorded values are considered to be representative of normal background conditions.

3.6 *GIARDIA / CRYPTOSPORIDIUM*

Giardia and *Cryptosporidium* samples were not collected by Environmental Quality staff during 2006 and no additional sampling is planned for the future. Data have been collected from a variety of locations in previous years, but no clear seasonal trends were determined and presence or absence appears to be related more to precipitation, flow conditions, and presence of wildlife or farm animals rather than season.

4.0 RESULTS OF RESERVOIR MONITORING PROGRAM

4.1 BACTERIA

Samples were collected Monday through Friday by MWRA staff from the John J. Carroll Water Treatment Plant at Walnut Hill in Marlborough and weekly from an internal tap at the Cosgrove Intake in Clinton. EPA's fecal coliform criteria for drinking water require that at least ninety percent of all source water samples contain less than 20 colonies per 100mL. One hundred percent of the 255 samples collected at Walnut Hill and the 52 samples collected at the Cosgrove Intake contained less than the standard, with a maximum value of 18 colonies per 100mL recorded on January 4th. This is the second consecutive year that all samples have been in compliance with the standard. DCR put considerable effort into developing and implementing a rigorous bird harassment program, and the results in 2006 were again outstanding.

Bacterial transect samples were collected from twenty-three surface stations across the reservoir to document the relationship between seasonal bacteria variations and visiting populations of gulls, ducks, geese, and other waterfowl. Data were also used to judge the effectiveness of bird harassment activities. Sample locations were illustrated previously on Figure B. Samples were collected monthly in January, March, April May, June, July, August, and September, twice monthly in February, October and November, and weekly in December. All fecal coliform transect data are included in Table 27 on the following page.

TABLE 27

FECAL COLIFORM TRANSECT DATA (colonies/mL)
Wachusett Reservoir - 2006

SITE	1/12	2/7	2/14	3/29	4/26	5/17	6/21	7/19	8/30	9/26	10/10	10/24	11/7	11/21	12/5	12/12	12/19	12/28
A-3	3	3	1	0	0	0	0	2	0	3	1	0	2	3	1	0	0	0
B-2	4	3	2	0	1	2	0	0	1	1	0	1	5	4	4	0	0	0
B-3	1	3	1	1	0	2	0	1	4	1	0	2	0	1	0	0	0	0
C-1	4	3	2	0	0	1	0	0	0	0	0	2	4	7	2	1	1	1
C-3	3	0	1	0	5	2	0	0	0	1	1	3	4	3	1	0	0	1
C-5	1	1	0	0	0	1	1	7	0	0	0	0	1	1	4	0	1	0
D-1	8					3	0	0	**22**	0	0	4	**10**	**17**	6	0	1	1
D-2	6	1	0	3	1	1	0	0	4	1	0	**13**	**14**	**>200**	0	1	0	0
D-4	4	4	2	0	0	1	0	0	3	2	2	0	2	**19**	1	2	1	0
E-2	9	5	2	4	0	1	0	5	2	1	0	**21**	**22**	**26**	7	0	0	1
E-4	10	4	5	0	0	0	0	1	2	2	1	1	9	1	2	2	1	0
F-2	**24**	7	**12**	1	0	1	0	1	1	1	0	5	**14**	6	4	2	4	0
F-3	4	0	2	0	0	2	0	0	3	2	2	**16**	**24**	3	5	1	0	0
F-4	7	2	0	0	0	2	0	1	1	0	0	7	8	2	8	0	0	0
G-2	**37**	**35**	**28**	1	0	2	0	8	3	1	2	0	2	7	**120**	6	**11**	**18**
H-2	**39**	**84**	**22**	0	0	0	0	1	**12**	**22**	1	1	9	3	2	**14**	**17**	**22**
I-2	**67**	**83**	**58**	1	1	3	0	2	**30**	0	6	2	7	**11**	**15**	**19**	**34**	**38**
J-2	**42**		**33**	2	0	0	0	1	**16**	3	1	0	3	6	**30**	**23**	**11**	**23**
J-3	**70**	**38**	**44**	3	0	1	0	2	3	5	1	3	6	**247**	**36**	**38**	**24**	**63**
J-4	**107**		**75**	1	0	2	0	0	9	**12**	1	3	**23**	**36**	**74**	**116**	**81**	**119**
K-2	**95**	**22**	**86**	5	0	3	0	5	2	0	0	4	**18**	**19**	**137**	**106**	**92**	**362**
M-1	**28**	**21**	**31**	2	0	**24**	3	1	1	2	0	2	2	**21**	**40**	**40**	**53**	**22**
N-1	**17**	**23**	**34**	6	1	6	0	0	1	5	3	3	**13**	**17**	**120**	**69**	**78**	**36**

Samples collected in January and February 2006 reflected normal winter conditions prior to the reservoir freezing over. The harassment program had successfully moved birds away from the north end of the reservoir near the intake and roosting birds (and high fecal coliform levels) were concentrated to the south. The reservoir froze over completely on March 7^{th} but remained ice covered only a few days.

No stations anywhere in the reservoir contained more than ten fecal coliform colonies per 100mL from March through October except for an occasional sample with up to thirty colonies per 100mL near mid reservoir and at the southern end of the reservoir in May, August, September, and October. Fecal coliform concentrations at mid reservoir and at the southern part of the reservoir increased dramatically in November and one station north of the narrows (the 'bird-free' zone) contained more than two hundred fecal coliform colonies per 100mL. Harassment activities were increased and concentrations north of the narrows declined, with no samples from that area containing more than ten colonies per 100mL for the remainder of the year. The number of birds and the number of bacteria remained high in the southern part of the reservoir in December, and samples containing more than one hundred fecal coliform colonies per 100mL were not uncommon.

4.2 WATER COLUMN CHARACTERISTICS

4.2.1 FIELD PROCEDURES

DCR staff routinely measure water column profiles in the Wachusett Reservoir for the following hydrographic parameters: temperature, specific conductance, dissolved oxygen concentration, percent oxygen saturation, and hydrogen ion activity (pH). This involves use of a field instrument to record data starting at the surface and then recording repeated measurements as the instrument is gradually lowered to the bottom. Measurements are recorded at one meter intervals, except during periods of isothermy and mixing (generally November through March) when intervals of two or three meters are adequate to characterize the water column.

Typical of most deep lakes and reservoirs in the temperate region, Wachusett Reservoir becomes thermally stratified in summer. Water column stratification in summer is characterized by a layer of warm, less dense water occupying the top of the water column ("epilimnion"), a middle stratum characterized by a thermal gradient or thermocline ("metalimnion"), and a stratum of cold, dense water at the bottom ("hypolimnion"). Profile measurement during this period of thermal stratification is important for many reasons including the following: (1) to monitor phytoplankton growth conditions and detect "blooms" of potential taste and odor causing organisms associated with discrete strata of the water column (see section on phytoplankton), (2) to track the progress of the Quabbin "interflow" through the Wachusett basin during periods of water transfer (see below), and (3) to monitor water quality within each stratum and determine appropriate depths for vertically stratified nutrient sampling.

Water column profiles are measured using a "Reporter" or "H20" multiprobe and "Surveyor 3" water quality logging system manufactured by Hydrolab Corporation (now a component of the Hach Company located in Loveland, Colorado). These instruments are routinely charged and calibrated during the field season. At the conclusion of field work, data recorded by the logging system are downloaded to a PC in an Excel spreadsheet.

Profiles are measured weekly at Basin North/Station 3417 in conjunction with routine plankton monitoring (see Section 4.4) during the stratification period. This station is representative of the deepest portion of the reservoir basin and it is not influenced by turbulence from local water inputs or withdrawals that could disrupt profile characteristics. Profiles measured in Thomas Basin and at Cosgrove Intake (Station 3409) are usually influenced by inflow from the Quabbin Aqueduct and withdrawal at the Cosgrove Intake respectively.

4.2.2 THE QUABBIN "INTERFLOW" IN WACHUSETT RESERVOIR

The transfer of water from Quabbin to Wachusett Reservoir via the Quabbin Aqueduct has a profound influence on the water budget, profile characteristics, and hydrodynamics of the Wachusett Reservoir. During the years 1995 through 2006, the amount of water transferred annually from Quabbin to Wachusett ranged from a volume equivalent to 44 percent of the Wachusett basin up to 94 percent. The period of peak transfer rates generally occurs from June through November. However, at any time of the year, approximately half of the water in the Wachusett basin is derived from Quabbin Reservoir.

The peak transfer period overlaps the period of thermal stratification in Wachusett and Quabbin Reservoirs. Water entering the Quabbin Aqueduct at Shaft 12 is withdrawn from depths of 13 to 23 meters in Quabbin Reservoir. These depths are within the hypolimnion of Quabbin Reservoir where water temperatures range from only 9 to 13 °C in the period June through October. This deep withdrawal from Quabbin is colder and denser relative to epilimnetic waters in Wachusett Reservoir. However, due to a slight gain in heat from mixing as it passes through Quinapoxet Basin and Thomas Basin, the transfer water is not as cold and dense as the hypolimnion of Wachusett. Therefore, Quabbin water transferred during the period of thermal stratification flows conformably into the metalimnion of Wachusett where water temperatures and densities coincide.

The term interflow describes this metalimnetic flow path for the Quabbin transfer that generally forms between depths of 7 to 15 meters in the Wachusett water column. Interflow water quality is distinctive from ambient Wachusett water having lower specific conductivity characteristic of Quabbin Reservoir. Multiprobe measurements of conductivity readily distinguish the flow path of Quabbin water as it is transferred to Wachusett. The interflow penetrates through the main basin of Wachusett Reservoir (from the Route 12 Bridge to Cosgrove Intake) in approximately three to four weeks depending upon the timing and intensity of transfer from Quabbin. The interflow essentially connects Quabbin inflow to Cosgrove Intake in a "short circuit" undergoing limited mixing with ambient Wachusett Reservoir water.

In 2006, a sustained transfer was initiated on July 7th and was continuous through October 27th except for a four day interruption from September 28th through October 1st. A deflection in the conductivity profile to lower values was detected at Basin North/3417 on July 24th (see Section 4.2.4 below) followed by similar instrument readings in Cosgrove Intake on July 29th signifying complete interflow penetration through the main basin in a time interval of 23 days from transfer initiation.

By September, the interflow stratum had developed into a configuration slightly more expansive than typical with a thickness of eleven meters forming between 6 and 17 meters deep. At the conclusion of 2006, the transfer volume totaled 34,204 million gallons (129 million cubic meters), equivalent to 52 percent of the capacity of Wachusett Reservoir. The influence of the 2006 Quabbin interflow on profile characteristics in Wachusett Reservoir is discussed in the sections that follow.

4.2.3 TEMPERATURE PROFILES

Thermal stratification of the water column and the presence of the interflow stratum are major determinants of vertical gradients and patterns evident in profile measurements. Temperature profiles that illustrate the development of thermal stratification due to solar radiation and atmospheric warming in spring and summer and the subsequent loss of heat leading to fall turnover are depicted in conjunction with profiles of other hydrographic parameters in Figures 1 through 3 below.

An early stage of thermal stratification was evident on the June 19th measurement date when a gradual gradient spanning a difference of approximately 13°C existed between the top and bottom of the water column. The top of the water column continued to gain heat and by July 24th a well-defined epilimnion had formed to a depth of 5 meters with a temperature of 25°C.

Highest temperatures in the epilimnion were recorded on August 3rd (Figure 3) at about 27 °C while temperatures in the hypolimnion remained at about 9 °C throughout the summer. The September 11th profile (Figures 1 and 2) showed that the system had started to lose heat and the epilimnion had cooled to about 20°C as radiation intensities and air temperatures diminished.

The establishment of the interflow could be seen in the profile measured on August 3rd. A very steep thermal gradient existed between depths of six and eight meters in which the temperature dropped 12°C. This steep gradient in temperature and density caused by the interflow stabilized the position of the metalimnion between depths of approximately 6 and 17 meters. The presence of the interflow was also evident in the temperature profile of September 11th as a pronounced flattening or plateau in the thermocline between 10 and 12 meters where the temperature centered around 14°C. This plateau represents the "core" of the interflow stratum that undergoes minimal mixing with ambient Wachusett water.

The profile measured on October 19th (Figure 3) shows that heat losses and wind energy had caused the water column to be mixed down to a depth of 13 meters, thus homogenizing the epilimnion and most of the metalimnetic interflow. A difference of about 4°C existed between the top and bottom of the water column at this time. A week later, on October 26th (Figures 1 and 2), this process had continued with the water column now homogenized down to a depth of 22 meters and only 2°C difference between top and bottom. A few days later, wind energy dispersed the remnant stratification pattern and mixed the entire water column in an event known as fall "turnover." The water column was shown to be essentially isothermal at around 11°C in a profile recorded on October 31st.

4.2.4 SPECIFIC CONDUCTANCE

Specific conductance ("conductivity") profiles in Wachusett Reservoir reflect the interplay between native water contributed from the Wachusett watershed and water transferred from Quabbin. The Quinapoxet and Stillwater Rivers are the two main tributaries to Wachusett Reservoir and are estimated to account for approximately 75 percent of annual inflow from the reservoir watershed. Measurements of conductivity in these rivers generally range between 60 and 240 uS/cm with an average value between 125 and 150 uS/cm. In contrast, the average conductivity value of Quabbin water is approximately 40 uS/cm.

During periods of isothermy and mixing (November through March), conductivity values throughout the main Wachusett basin typically range from 75 to 145 uS/cm depending on the amount of water received from Quabbin the previous year. During the summer stratification period the Quabbin interflow is conspicuous in profile measurements as a metalimnetic stratum of low conductivity. Figure 1 depicts conductivity profiles measured at Basin North/3417 from June through October.

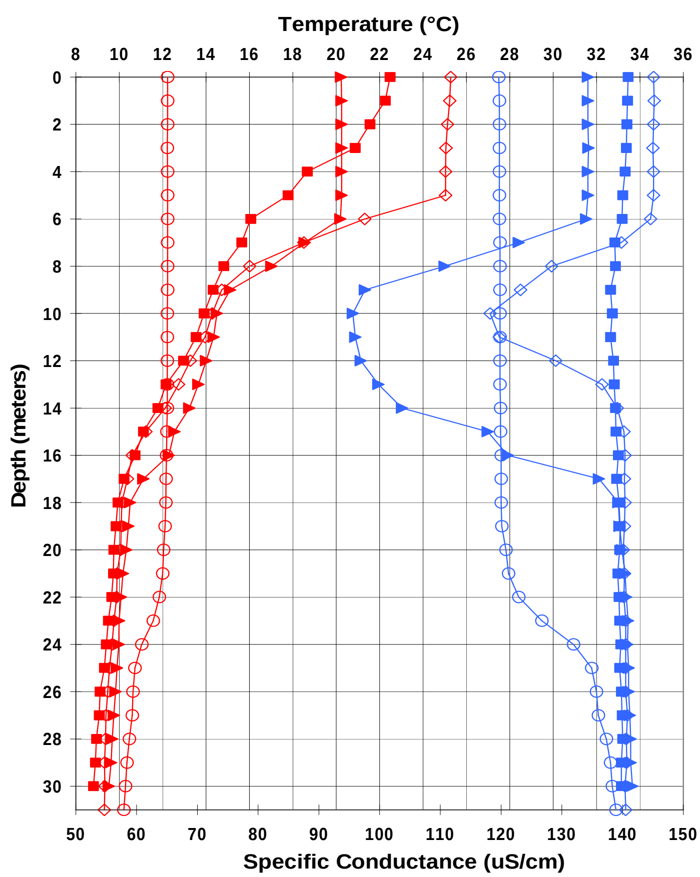


Figure 1 – Temperature and Specific Conductance Profiles at BN/3417

LEGEND

Red = Temperature (°C)
Blue = Specific Conductance (uS/cm)

DATES:
Squares = 6/19/06
Diamonds = 7/24/06
Triangles = 9/11/06
Circles = 10/26/06

On June 19^{th}, before the Quabbin transfer was initiated, conductivity values ranged around 140 uS/cm throughout the water column. The profile recorded on July 24^{th} (17 days after transfer initiation) shows an early stage in the development of the interflow stratum as an indentation or "trough" in the conductivity profile between depths of 6 and 14 meters. This trough intensifies (extends to lower conductivity values) over the period of transfer as water in the interior of the interflow undergoes less mixing with ambient reservoir water at the boundaries of the interflow stratum. By September 11^{th}, the interflow stratum occupied 11 meters of the water column between depths of 6 and 17 meters and a minimum interflow conductivity value of 95.6 uS/cm was observed at a depth of 10 meters (Figure 1).

Profiles measured on October 26^{th} show that heat losses and wind energy had caused the water column to be mixed down to a depth of 22 meters and homogenizing the epilimnion, the metalimnetic interflow stratum, and the upper portion of the hypolimnion. The conductivity of this mixed portion of the water column was 120 uS/cm. By the end of October, wind energy had dispersed the remnant stratification pattern causing conductivity in the entire water column to register around 121 uS/cm.

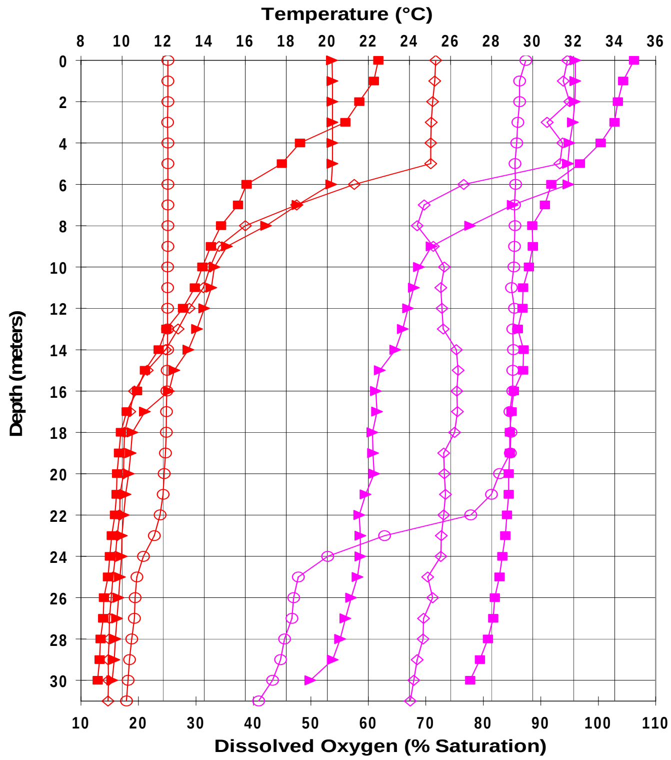
4.2.5 DISSOLVED OXYGEN

Measurement of dissolved oxygen profiles throughout the year usually show values ranging from 60 to 100 percent saturation at ambient water temperatures. Saturation values in the epilimnion remained around 90 percent or more throughout the year, whereas saturation values in the metalimnion and hypolimnion declined progressively from June through October (Figure 2).

During the period of thermal stratification, demand for oxygen in the hypolimnion reduced oxygen concentrations to between 40 and 60 percent saturation before fall turnover in late October replenished oxygen throughout the water column. Reductions in oxygen concentration are also evident in the metalimnion during the stratification period, but these are mainly indicative of oxygen demand within the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir. Relatively low saturation values measured near the bottom of the water column indicate slightly higher rates of oxygen consumption by microbial decomposition processes occurring at the sediment-water interface.

Completely absent this year were profile spikes in dissolved oxygen concentrations localized near the interface between epilimnion and metalimnion. Photosynthetic activity by phytoplankton aggregated near this interface can boost dissolved oxygen above saturation concentrations and this phenomenon has been observed intermittently in profiles recorded over years of monitoring. The most remarkable example of this occurred in 2004 when a dense metalimnetic aggregation of the colonial, flagellated chrysophyte *Chrysosphaerella* was evident in profile measurements as a discrete spike in dissolved oxygen saturation values up to 109.6 percent that persisted around a depth of 7.5 meters from early July through mid-August (see 2004 annual report).

Figure 2 – Temperature and Dissolved Oxygen Profiles at BN/3417



LEGEND

Red = Temperature (°C)
Purple = Dissolved Oxygen (% Sat.)

DATES:
Squares = 6/19/06
Diamonds = 7/24/06
Triangles = 9/11/06
Circles = 10/26/06

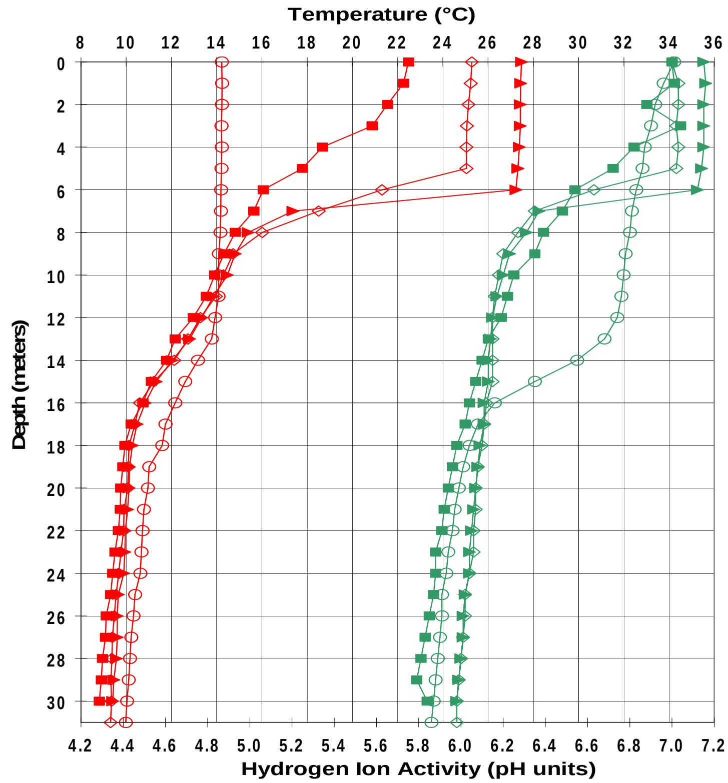
The profile measured on October 26th shows homogenization of the water column to a depth of 22 meters with attendant replenishment of oxygen to around 85 percent saturation throughout the mixed stratum. By the end of October, wind energy dispersed the remnant stratification pattern, mixing and exposing the entire basin volume to the atmosphere, thereby replenishing dissolved oxygen concentrations to around 87 percent saturation at all depths.

4.2.6 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity (pH) in Wachusett Reservoir is determined ultimately by the exchange of inorganic carbon between the atmosphere and water (the carbon dioxide-bicarbonate-carbonate "buffering system"). Specific patterns of pH distribution vertically in the water column and seasonally over the year are mainly determined by the opposing processes of photosynthesis and respiration. Wachusett Reservoir pH values range from around neutral (pH=7) to slightly acidic (pH=6). Figure 3 depicts pH profiles measured at Basin North/3417 from June through October.

Epilimnetic values of pH generally remained near neutral throughout the year. Values slightly greater than neutral result from photosynthetic activity by phytoplankton inhabiting this most productive stratum of water. Photosynthesis results in the uptake of carbon dioxide dissolved in the water and this removal of carbon dioxide tends to increase pH in the epilimnion where photosynthetic activity is greatest. Metalimnetic values of pH ranged from 6.0 to 6.5 during most of the stratification period, but these are mainly indicative of the Quabbin interflow and the Quabbin Reservoir rather than processes occurring within Wachusett Reservoir.

Figure 3 - Temperature and Hydrogen Ion Activity Profiles at BN/3417



LEGEND

Red = Temperature (°C)
Green = Hydrogen Ion Activity (pH)

DATES:
Squares = 6/19/06
Diamonds = 7/24/06
Triangles = 8/03/06
Circles = 10/19/06

In contrast to the utilization of carbon dioxide by photosynthetic organisms, microbial decomposition of organic matter produces carbon dioxide. In the hypolimnion, where microbial respiration is the dominant process, the production of carbon dioxide tends to decrease pH. Hypolimnetic pH declined during the period of thermal stratification reaching a value of 5.9 by October 19th. Also evident on this date is the restoration of pH values to 6.9 in the mixed stratum above a depth of 13 meters due to the erosion of stratification structure by heat losses and wind energy. Mixing of the entire basin volume associated with “turnover” in late October restored equilibrium conditions with the atmosphere resulting in pH values ranging from 6.7 to 7.0 throughout the water column.

4.3 NUTRIENTS

4.3.1 FIELD PROCEDURE

Quarterly sampling for measurement of nutrient concentrations in Wachusett Reservoir has been conducted since the conclusion of the program of monthly sampling from October 1998 through September 1999. Quarterly sampling was conducted at the onset of thermal stratification (May), in the middle of the stratification period (July), near the end of the stratification period (October), and during a winter period of mixis before ice cover (December). Samples were collected at three of the main monitoring stations used in the 1998-99 year of study (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure A).

Samples were collected in the epilimnion, metalimnion, and hypolimnion during the period of thermal stratification and near the top, middle, and bottom of the water column during mixis. Water column profiles of temperature, dissolved oxygen, and other parameters measured with a multiprobe were evaluated in the field to determine depths for metalimnetic samples.

Quarterly sampling continued to be performed in collaboration with MWRA staff at the Deer Island Central Laboratory who provided sample containers and where all grab samples were sent for analysis. Sampling protocol, chain-of-custody documentation, and sample delivery were similar to those established in the 1998-99 year of study. Details of sampling protocol are provided in the comprehensive report on Wachusett Reservoir nutrient and plankton dynamics (Worden and Pistrang, 2003).

Modifications to the quarterly sampling program have consisted only of a lower minimum detection limit for total Kjeldahl-nitrogen (reduced to 0.05 mg/L from previous limits of 0.2 and 0.6 mg/L) and the addition of UV254 absorbance (in 2000) and dissolved silica (in 2004) among the parameters to be measured. Measurement of UV absorbance at a wavelength of approximately 254 nanometers serves as is a relative assay of the concentrations of organic compounds dissolved in the water. Samples to be analyzed for dissolved silica are field filtered (0.45μm membrane) and these measurements complement conventional silica analyses that have been conducted since the beginning of the sampling program.

4.3.2 RESULTS OF NUTRIENT ANALYSES

The nutrient database for Wachusett Reservoir established in the 1998-99 year of monthly sampling and subsequent quarterly sampling through 2005 is used as a basis for interpreting data generated in 2006. Most results from quarterly sampling in 2006 document concentrations and intensities that register almost entirely within historical ranges for all parameters except silica and UV254 absorbance (Table 28; complete quarterly database located in Appendix).

Silica concentrations in the main basin attained record maximums and these increases were inversely correlated with total phosphorus concentrations. Results for total phosphorus were notable with concentrations below the minimum laboratory detection limit of 5 μg/L throughout the main basin, initially observed in December 2005 and continuing through the May 8, 2006 sampling date. Assuming that concentrations did not spike between these sampling dates, the data indicate that extremely low phosphorus concentrations persisted throughout the main basin of the reservoir for five months. This episode is unique in the historical database.

The consistently low phosphorus concentrations reflect the constant and intense demand for this nutrient by phytoplankton and reaffirm previous findings identifying phosphorus as the nutrient limiting phytoplankton growth within Wachusett Reservoir. The limitation of phytoplankton productivity by a deficiency of phosphorus relative to other nutrients is typical of most temperate lakes and reservoirs.

Table 28 - Wachusett Reservoir Nutrient Concentrations:

Comparison of Ranges from 1998-05 Database[1] to Results from 2006 Quarterly Sampling [2]

Sampling Station [3]	Ammonia (NH3; ug/L)		Nitrate (NO3; ug/L)		Silica (SIO2; mg/L)		Total Phosphorus (ug/L)		UV254 (Absorbance/cm)	
	1998-05	Quarterly'06	1998-05	Quarterly'06	1998-05	Quarterly'06	1998-05	Quarterly'06	1998-05	Quarterly'06
Basin North/3417 (E)	<5 - 13	<5 - 13	<5 - 159	42 - 176	0.59 - 3.34	2.48 - 4.62	<5 - 17	<5 - 10	0.032 - 0.081	0.060 - 0.089
Basin North/3417 (M)	<5 - 36	8 - 34	<5 - 164	79 - 180	0.77 - 3.65	3.17 - 4.67	<5 - 20	<5 - 10	0.032 - 0.084	0.057 - 0.102
Basin North/3417 (H)	<5 - 41	9 - 19	48 - 225	88 - 204	1.27 - 4.11	4.03 - 5.06	<5 - 17	<5 - 8	0.032 - 0.080	0.069 - 0.083
Basin South/3412 (E)	<5 - 14	<5 - 15	<5 - 172	41 - 176	0.56 - 3.84	2.48 - 4.58	<5 - 20	<5 - 11	0.031 - 0.095	0.060 - 0.098
Basin South/3412 (M)	<5 - 39	7 - 24	11 - 184	82 - 181	0.95 - 4.03	3.25 - 4.80	<5 - 22	<5 - 9	0.032 - 0.094	0.052 - 0.100
Basin South/3412 (H)	<5 - 44	11 - 20	49 - 224	104 - 186	1.64 - 4.13	4.35 - 4.78	<5 - 37	<5 - 9	0.036 - 0.092	0.067 - 0.108
Thomas Basin (E)	<5 - 18	<5 - 15	<5 - 201	32 - 196	0.62 - 5.11	2.71 - 7.44	<5 - 27	8 - 17	0.026 - 0.305	0.041 - 0.201
Thomas Basin (M)	<5 - 27	<5 - 17	<5 - 205	30 - 213	0.88 - 5.20	2.54 - 7.36	<5 - 24	9 - 18	0.026 - 0.301	0.037 - 0.200
Thomas Basin (H)	<5 - 57	11 - 18	<5 - 236	30 - 200	0.92 - 5.35	2.58 - 7.39	<5 - 24	7 - 17	0.027 - 0.289	0.035 - 0.204

Notes: (1) 1998-05 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling through December 2005, except for measurement of UV254 initiated in 2000 quarterly sampling

(2) 2006 quarterly sampling conducted May, July, October, and December

(3) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

A plausible explanation for the record maximum silica concentrations measured in 2006 is that diatoms were constrained by an exceptional scarcity of phosphorus (noted above) and that the typical processes of diatom growth, frustule formation, and sedimentation did not function to remove as much silica from the water column as usual (see Worden and Pistrang, 2003 for details of silica dynamics in Wachusett Reservoir). This interpretation is corroborated by plankton monitoring data that document unusually subdued activity by diatoms during the spring of 2006.

A spring diatom bloom is typically a regular feature of Wachusett plankton dynamics with densities often exceeding 1,000 ASUs/ml. Spring of 2005 provides the most recent example as diatoms proliferated to a maximum density of 3,168 ASUs/ml. In contrast, diatom populations in 2006 reached a maximum density of only 546 ASUs/ml on April 4^{th}. The record silica concentrations measured in the main basin likely comprise an enhanced pool of residual silica remaining unused by phosphorus-deficient diatoms.

Record maximum silica concentrations were also observed in Thomas Basin on the December 12, 2006 sampling date. Diatom population dynamics weakened by a deficiency of phosphorus may contribute to these high silica concentrations (similar to the main basin as discussed above), but concentrations recorded in Thomas Basin mostly reflect the higher concentrations delivered by the Quinapoxet and Stillwater Rivers.

The Quinapoxet and Stillwater Rivers are the major tributaries to Wachusett Reservoir, draining approximately 75% of the total watershed area, and they discharge and mix in Thomas Basin before flowing into the main reservoir basin. The high December silica concentrations in Thomas Basin reflect the relatively high loading rates from these tributaries and, coincidentally, the absence of water transferred from Quabbin. The annual transfer from Quabbin functions to dilute and ameliorate the influence of the rivers on water quality, but river influence quickly resume ascendancy in Thomas Basin when the transfer is terminated. The 2006 transfer was terminated on October 27^{th}, so Thomas Basin received river inputs exclusively from that time until the December 12^{th} sampling date (the transfer was resumed briefly in late December, but after nutrient sampling was completed).

In the three previous years (2003-05), ice cover or other factors prevented December sampling efforts in Thomas Basin and it is likely that similar elevated values would have been observed if December measurements had been obtained in prior years. In summary, the elevated silica values measured in December samples from Thomas Basin demonstrate river influence on water quality operating in the absence of the Quabbin transfer and recorded only infrequently (not since 2002) due to constraints on sampling imposed by winter conditions.

UV254 absorbance also attained record maximums in the main basin during 2006. The data indicate that elevated UV254 absorbance measured at Basin North/Station 3417 is derived from a “plug” of water laden with dissolved organic compounds originally discharged to Thomas Basin by record amounts of river runoff in October of 2005 resulting from more than twelve inches of rainfall in a nine day period. This "plug" subsequently entered the main basin of the reservoir and was observed at record UV254 intensities at Basin South/Station 3412 on December 14, 2005. In 2006 residual compounds from this "plug" have been transported through the main basin and reached Basin North/Station 3417. Record UV254 absorbance was recorded in the epilimnion and metalimnion at this location during an early stage of interflow penetration on July 25th.

At Basin South/Station 3412, ranges for UV254 absorbance increased slightly over records set last year due to intensities measured in samples collected on December 12th. Relatively high UV absorbance was also observed in Thomas Basin on this date. Similar to the results for silica discussed above, the ascendancy of river influence with no Quabbin transfer from October 27th until the December 12th sampling date increased loading of dissolved organic compounds to Thomas Basin and caused UV254 absorbance to increase. Flow out of Thomas Basin delivered some of these UV-absorbing compounds into the main basin where they dispersed downgradient and contributed to the record measurements recorded at Basin South/Station 3412 on December 12th.

The patterns of nutrient distribution in 2006 quarterly samples correspond closely to those documented in the comprehensive report on Wachusett Reservoir nutrient and plankton dynamics (Worden and Pistrang, 2003). These patterns consist most importantly of the following: (1) prominent seasonal and vertical variations with low epilimnetic concentrations in summer resulting from phytoplankton uptake and higher concentrations accumulating in the hypolimnion due to microbial decomposition of sedimenting organic matter, (2) interannual fluctuations in nutrient concentrations and parameter intensities occurring across the main basin as a result of the divergent influences of the Quabbin transfer and the Wachusett watershed with temporary lateral gradients becoming pronounced for nitrate, silica, UV254, and conductivity, either increasing or decreasing downgradient of Thomas Basin depending on the dominant influence.

Reference Cited

Worden, David and Larry Pistrang. 2003. Nutrient and Plankton Dynamics in Wachusett Reservoir: Results of the MDC/DWM's 1998-2002 Monitoring Program, a Review of Plankton Data from Cosgrove Intake, and an Evaluation of Historical Records. Metropolitan District Commission, Division of Watershed Management.

4.4 PHYTOPLANKTON

4.4.1 FIELD PROCEDURES

Sampling from a boat at Basin North/Station 3417 during the late-April through early-November thermal stratification period has been a key element of phytoplankton monitoring since 2003 when new staff assignments and procedures were implemented. Boat sampling replaced the previous method of collecting grabs at various depths from the catwalk at the rear of Cosgrove Intake. Basin North/Station 3417 is representative of the deepest portion of the basin and it is not influenced by seiche effects or turbulence from water withdrawals which can destabilize stratification boundaries and obscure associated phytoplankton growth patterns at Cosgrove Intake. Samples collected at Cosgrove Intake are adequately representative of the main basin during the late-November through early-April period of mixis when the water column is homogenous, however, so sampling is conducted from the catwalk during this period if ice conditions permit.

Sampling frequency is generally weekly in early spring, fall, and winter increasing to twice a week (usually Monday and Thursday) during the period from May through September when episodes of rapid population growth ("blooms") by problematic "taste and odor" organisms generally occur. Samples are usually collected at two depths which varies slightly between periods of mixis and stratification. During periods of mixis, samples are collected as follows: (1) near the top of the water column at a depth of three meters and (2) at a depth of eight meters corresponding to the upper intake depth at Cosgrove. During the annual stratification period samples are collected as follows: (1) near the middle of the epilimnion at a depth of three meters and (2) near the bottom of the epilimnion at a depth of six meters, and (3) within strata pinpointed by distinctive profile measurements (see below). Additionally, surface samples are collected in June and July when a bloom of the cyanophyte *Anabaena* frequently accumulates at the surface. Samples are collected using a Van Dorn Bottle and returned to the laboratory for concentration and microscopic analysis (details given below in next section).

In addition to grab sampling, routine phytoplankton monitoring during the stratification period also includes measurement of hydrographic parameters such as temperature, dissolved oxygen, hydrogen ion activity (pH), and specific conductance with a Hydrolab multiprobe (see section on water column profile measurements). These parameters are measured at one meter intervals as the multiprobe is lowered from the surface to record a profile of the entire water column. Secchi transparency is also recorded as an approximate measure of the amount of particulates, mostly plankton, suspended in the water column.

During the stratification period, when spikes in dissolved oxygen concentrations in profile measurements (a "positive heterograde curve") indicate photosynthetic activity associated with a phytoplankton bloom or aggregation within a specific stratum of the water column, an additional grab sample is collected at that depth to identify and quantify the bloom organism. Motile colonial chrysophytes ("golden-brown algae") such as *Chrysosphaerella*, *Dinobryon*, and *Synura* are generally responsible for subsurface blooms in Wachusett Reservoir and the "bloom stratum" that they prefer is generally between six and eight meters coincident with the steep temperature gradient at the interface between the epilimnion and the metalimnetic interflow.

Productivity by phytoplankton during the stratification period is almost exclusively restricted to the epilimnion and its boundary with the metalimnetic interflow (motile chrysophytes generally aggregate within upper margin of the metalimnion no deeper than eight meters). The absence of significant photosynthetic activity below the epilimnion/interflow boundary has been documented consistently since 1987 by multiprobe measurements of water column profiles. Steadily declining concentrations of dissolved oxygen below this boundary over the weeks of the stratification period indicate that microbial decomposition of sedimenting organic matter is the dominant biological activity. It is likely that the steep temperature and density gradients at this boundary prohibit inoculation and/or dispersion of photosynthetic organisms into the metalimnetic interflow.

4.4.2 LABORATORY CONCENTRATION AND MICROSCOPIC ANALYSIS OF PLANKTON

Prompt acquisition of information on phytoplankton densities is critical for agency decision-making on the need for algaecide applications to avoid taste and odor problems. The method of sand filtration for concentration of phytoplankton samples has long been in use by both MWRA and DWSP because it enables relatively rapid analysis of samples while subjecting organisms to minimal damage or distortion. The specific method used is documented in Standard Methods Twelfth Edition (1965, pages 669-671; photocopies kindly provided by Warren Zepp of MWRA). In brief, the method entails gravity filtration of sample water placed in a funnel through a layer of fine sand followed by washing and gentle shaking of the sand with waste filtrate water in a beaker to detach organisms from the sand grains, and lastly, prompt decanting of the concentrated sample after the sand has been allowed to settle. A portion of the concentrated sample is then analyzed microscopically using quantitative techniques as presented below.

Phytoplankton taxa in concentrated samples are enumerated using a Sedgewick-Rafter (S-R) Cell which enables phytoplankton densities to be quantified. Each concentrated sample is mixed to homogenize the sample and then 1 ml of the sample is withdrawn with a pipette and placed into the S-R Cell. Initial inspection of phytoplankton within the S-R Cell is accomplished with a stereozoom dissecting microscope capable of magnification from 7 to 45 times. Use of this instrument to scan the entire S-R Cell is important to detect colonies of certain motile taxa present at low densities such as *Synura* and/or colonies floating against the underside of the coverslip such as *Anabaena*. Analysis of surface samples collected in June and July is limited to scanning unless *Anabaena* is detected at densities amenable to enumeration using a compound microscope (see below).

Scanning of the entire S-R cell enables colonial “taste and odor” organisms to be detected and quantified at very low densities. Colonies observed in the S-R Cell using the stereozoom dissecting microscope are quantified by counting the number of colonies and then measuring their average diameter using a compound microscope (see below). This information, along with the known concentration factor arising from sand filtration, is used to calculate and express densities of colonial “taste and odor” organisms as Areal Standard Units (see below).

After the scanning procedure described above, microscopic analysis of phytoplankton samples is next performed with a compound microscope at a magnification of 200X using either bright field or phase-contrast illumination. Approximately 15 minutes are allowed for the phytoplankton to settle to the bottom of the S-R Cell before enumeration. Phytoplankton are enumerated in a total of 10 fields described by an ocular micrometer. The area of the ocular field is determined by calibration with a stage micrometer and the fields are selected for viewing at approximately 0.5 cm intervals across the length of the S-R Cell.

Phytoplankton densities are expressed as Areal Standard Units (ASU; equivalent to 400 square microns) per milliliter. The area of each specimen viewed in each counting field is estimated using the ocular micrometer (the ocular field is divided into a 10 by 10 grid, each square in the grid having a known area at 200X magnification). In the case of taxa which form gelatinous envelopes or are enclosed in a colonial mucilage, such as *Microcystis*, the area of the envelope is included in the estimate for that specimen. The areal extent of certain colonial taxa, such as the diatoms *Asterionella* and *Tabellaria*, is estimated by measuring the dimensions of one cell and multiplying by the number of cells in the colony. Cell fragments or structures lacking protoplasm, including lorica of *Dinobryon*, diatom frustules, and thecae of dinoflagellates, are not included in the count.

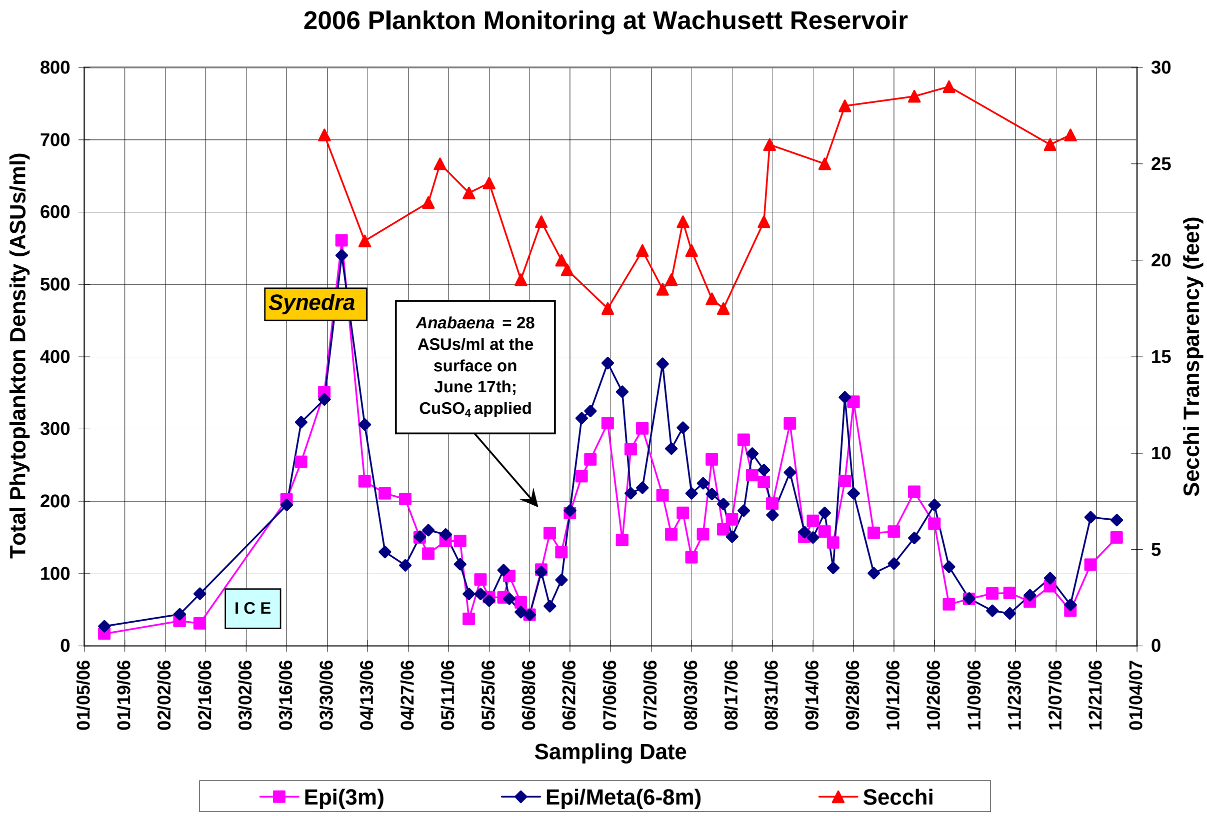
4.4.3. MONITORING RESULTS

Monitoring results for 2006 document a remarkably uneventful year starting with an unusually weak spring diatom bloom (Figure 4 below). A rapid expansion of diatom populations in spring is typically a regular feature of Wachusett plankton dynamics with densities often exceeding 1,000 ASUs/ml (see review given in Worden and Pistrang, 2003). Spring of 2005 provides the most recent example as diatoms proliferated to a maximum density of 3,168 ASUs/ml. In contrast, diatom populations (mostly *Synedra*) in 2006 reached a maximum density of only 546 ASUs/ml on April 4th. This subdued activity by diatoms is likely due to a deficiency of phosphorus in the water column (see previous section on nutrients). Diatoms declined rapidly following the modest April maximum and densities of all phytoplankton remained low in May.

The "taste and odor" cyanophyte *Anabaena* made its usual appearance in early June and attained a problematic density of 28 ASUs/ml in a typical surface accumulation on June 17th. This prompted MWRA to apply copper sulfate on the same day; the only application during 2006. Activity by *Cyclotella* and other diatoms caused densities to increase modestly in late June, but these declined through July and were succeeded by moderate densities of the colonial chlorophyte *Gloeocystis* in August. *Gloeocystis* persisted at moderate densities throughout September and was joined by the colonial cyanophyte *Aphanocapsa* and other cyanophytes at relatively low densities.

Densities of all phytoplankton declined to low values by November (less than 100 ASUs/ml) and generally remained low for the remainder of the year except for a slight resurgence of diatoms in late December with densities ranging from 113 to 169 ASUs/ml.

Figure 4



4.4.4. PLANKTON AND PERIPHYTON IN COVES OF WACHUSETT RESERVOIR

Plankton monitoring is routinely conducted in the main basin of the Wachusett Reservoir. Microscopic investigations of species diversity and relative abundance in the coves and inlets to the reservoir to date have not been done. The purpose of this study is to acquire additional knowledge of the taxonomic diversity, relative abundance, and community composition of portions of the reservoir not routinely surveyed and to document any dramatic fluctuations in the algal community that may lead to, or be indicative of, changes that may take place in the main body of the reservoir.

Beginning in May 2006, twelve coves were selected and sampling of periphyton and plankton was begun. Coves sampled are listed below.

Oakdale Basin- Railroad Tracks	Andrews Harbor
Upper Thomas Basin- Beaman Street Bridge	Hastings Cove
Thomas Basin Proper- Route 12	Lamson Cove
Quinnapoxet Basin- Railroad Tracks	West Boylston Brook Cove
Power Line Cove	Gates Brook Cove
Muddy Brook Cove	Malagasco Cove

Plankton are defined as aquatic organisms which may be either phytoplankton (plant) or zooplankton (animal). Plankton are suspended in the water and are generally microscopic in size. They form the basis of the food chain and are extremely susceptible to changes in nutrient levels and pollutants.

Periphyton are defined as organisms that grow on a substrate. These include but are not limited to, protozoa, bacteria, fungi, sponges, and algae. Periphyton species diversity and relative abundance in water systems are excellent indicators of water quality and are often used for water quality investigations. Subtle changes in species composition can be documented by routine sampling. Dramatic species shifts may be indicative of changes in water quality due to the addition of organic compounds or pollutants.

Field Procedure and Microscopic Analysis

All coves were sampled monthly from May 2006 until ice cover which occurred at the beginning of January 2007. At each sampling site, plankton were sampled using a net with an mesh size of 153 micrometers either towed horizontally under the surface at a depth of approximately 20 centimeters or from shore by throwing the net. Periphyton were sampled by scraping off organisms growing on submerged rocks, logs, or macrophytes using a pen knife.

Each sample was agitated prior to preparation of slide mounts for microscopic viewing. Two drops of the sample were placed on a clean glass slide and covered with a cover slip. The slide was scanned at low power for large organisms. Smaller organisms were observed using the higher magnification powers of a compound microscope. Relative abundance of organisms composing the sample was estimated using an established classification system (EPA, 1973).

Percent Composition of Each Taxa	**Relative Frequency Category**
60-100	**(A)** abundant
30-60	**(V)** very common
5-30	**(C)** common
1-5	**(O)** occasional
<1	**(R)** rare

Colonial organisms were counted as one colony equals one individual. Numbers of individuals within each colony were not counted.

Preliminary Results

A total of 115 different organisms were observed in samples and data analysis is ongoing. As a first step to recognizing broad patterns of seasonal dynamics among major taxa, species will be grouped into five classifications as follows: diatoms, zooplankton (cladocerans, copepods, rotifers and nauplii larvae), filamentous algae, taste and odor organisms (A*nabaena, Synura, Oscillatoria, Microcystis, Chrysosphaerella, Dinobryon*), and a miscellaneous category reserved for an organism that does not fit into any of the classifications listed but that becomes abundant during isolated sampling events. A detailed report on the results of this study will be published in the future.

Proposed Study Changes for 2007

In 2007, this study will be modified to enable quantitative measurement of plankton and periphyton densities. A subset of six coves from the original twelve was selected based on analysis of the data generated in 2006. Samples will be collected from Power Line Cove, Andrews Harbor, Hastings Cove, Lamson Cove, West Boylston Brook Cove, and Gates Brook Cove. Net sampling for plankton will be replaced by volumetric sampling using a Van Dorn Bottle. Plankton samples will be concentrated by sand filtration and analyzed quantitatively using a Sedgewick-Rafter Cell. Quantitative periphyton sampling will be accomplished using glass slides incubated in selected coves for a standard time period of four weeks. Upon retrieval, periphyton will be enumerated quantitatively based on field counts of organisms growing undisturbed on an area 22x22 mm of the intact slide or by scraping a one centimeter square area of the slide into a Sedgewick-Rafter Cell. Samples will be diluted with 1mL of water. These quantitative techniques will be used to determine the absolute abundance or density of organisms and further refine our understanding of cove dynamics.

Reference Cited

EPA, 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents (C.I. Weber, editor) EPA-670/4-73-001.

4.5 MACROPHYTES

4.5.1 THE THREAT OF EURASIAN WATER-MILFOIL

The Wachusett Reservoir system is a major component of the drinking water supply for greater Boston. In August of 2001, a pioneering colony of Eurasian Water-milfoil (*Myriophyllum spicatum;* referred to subsequently as "milfoil") was observed for the first time in Upper Thomas Basin, a small basin in the upper reaches of the reservoir system (Figure 1). Milfoil is an alien, invasive species of macrophyte known to aggressively displace native vegetation and grow to nuisance densities with associated impairments to water quality. Prior to 2001, this plant was restricted to the uppermost component of the reservoir system, Stillwater Basin, where its distribution has been monitored since 1999.

The expansion of milfoil into Upper Thomas Basin represented a significant increase in the risk of a potentially rapid and overwhelming dispersal of this plant into the main reservoir basin. The water quality implications of such an event are serious and include increases in water color, turbidity, phytoplankton growth, and trihalomethane (THM) precursors. These increases result from the function of this plant and macrophytes in general as nutrient "pumps," extracting nutrients from sediment and releasing them to the water column, mostly as dissolved and particulate organic matter.

This function is especially intense with milfoil due to its characteristically rapid and prolific growth habit. Nutrient release occurs during most life cycle stages, but especially during senescence and death. Milfoil also releases nutrients and organic matter during canopy formation (lower leaves and branches are sloughed as upper stems grow horizontally along the surface) and when undergoing a propagation process known as autofragmentation. Autofragments are stem segments with adventitious roots at the nodes that float upon abscission and are the plant's most important mode of reproduction and dispersal. Autofragments of milfoil eventually sink to the bottom and are capable of colonizing littoral zone areas having only minimal deposits of organic sediment.

Fanwort (*Cabomba caroliniana*) is another invasive alien plant that was restricted to Stillwater Basin in 1999, but which has since spread into Upper Thomas Basin. However, the spread of this plant was more gradual than that of milfoil. Control measures targeting both these alien species are discussed in the sections that follow.

4.5.2 WACHUSETT RESERVOIR MILFOIL CONTROL PROGRAM

The 2001 expansion of milfoil into Upper Thomas Basin prompted DCR to design a milfoil control program which was implemented in 2002 and, in collaboration with MWRA, has continued to the present. The main components of this program are the following: deployment of floating fragment barriers, deployment and maintenance of benthic barriers, annual hand-harvesting efforts, and routine scouting throughout the reservoir system by DCR to insure early detection of pioneering infestations (details of control efforts in previous years are provided in their annual reports). In recent years, fanwort has become as abundant as milfoil and both are targeted by annual control activities. Alien control efforts in 2006 consisted primarily of a continuation of the fundamental control technique of hand-harvesting conducted by staff from Aquatic Control Technology, Inc. (ACT). Details of the 2006 alien control program are summarized below.

<u>Hand-Harvesting of Alien Macrophytes: Summary of ACT Efforts in 2006</u>

- Preliminary GPS survey of Upper Thomas Basin and Thomas Basin proper on May 26th
- Hand-harvesting in "Powerline Cove," Thomas Basin proper, and Upper Thomas Basin conducted from July 10th through July 14th (total of 5 working days)
- Hand-harvesting in Upper Thomas Basin conducted from August 28th through September 1st (total of 5 working days)
- Hand-harvesting in Thomas Basin proper conducted on September 5th (1 day)
- Total diver-hours expended = 174 (compared to 97 in 2005, 135.5 in 2004, 93.25 in 2003, and 496.5 in 2002)
- Estimate of total milfoil plants removed = 6,937 (compared to 4,847 in 2005, 7,424 in 2004, 3,251 in 2003, and an estimated 75,000 - 100,000 milfoil plants removed in 2002)
- Estimate of total fanwort plants removed = 7,510 (compared to 860 in 2005 and 1,372 fanwort plants removed in 2004)
- Post-harvesting GPS survey of Upper Thomas Basin conducted on September 22nd documents only a few remaining scattered specimens of milfoil and fanwort, mostly in "hotspot cove" and on the "plateau" (also routine scouting by DCR finds no milfoil or fanwort in main basin)

In addition to the activities of consultants summarized above, DCR staff deployed floating fragment barriers (purchased in 2002) at strategic "bottleneck" locations to restrict the movement of milfoil autofragments into downgradient portions of the reservoir system. These locations are where floating fragment barriers were initially deployed in 2002 and consist of the railroad bridge between Stillwater Basin and Upper Thomas Basin and the Beaman Street Bridge between Upper Thomas Basin and Thomas Basin proper. In 2006, floating fragment barriers were deployed on March 29th (Stillwater railroad bridge) and April 6th (Beaman Street Bridge; repair to eyebolt attachment point required prior to deployment).

4.5.3 SUPPLEMENTAL ALIEN MACROPHYTE CONTROL ACTIVITIES

Additional scouting and documentation activities were conducted in 2006 in conjunction with the main components of the alien control program. Details of these activities are presented below.

Hy-Crest Pond, Sterling

Scouting of Hy-Crest Pond in Sterling, a potential source of the alien species Eurasian Water-milfoil and fanwort within the Stillwater River watershed, was conducted by DCR staff on October 17th. This effort consisted of visual observations of the littoral zone from a canoe. However, neither milfoil nor fanwort were observed in this pond (see table below for complete results).

Macrophyte Flora of Hy-Crest Pond, Sterling

Scientific Name	Common Name
Brasenia schreberi	Water-shield
Eleocharis sp.	Spike-rush
Eriocaulon sp.	Pipewort
Gratiola aurea	Golden-pert
Lemna sp.	Duckweed
Najas flexilis	Naiad
Nuphar variegata	Yellow Waterlily
Potamogeton amplifolius	Large-leaved Pondweed
Potamogeton robbinsii	**Robbins' Pondweed**
Potamogeton sp.	Thin-leaved Pondweed
Scirpus sp.	Woolgrass
***Sparganium* sp.**	**Bur-reed**
Utricularia sp.	Bladderwort
Wolffia sp.	Water-meal

Notes:
(1.) Dominant species indicated in **bold**.
(2.) Results based on visual observations conducted from a canoe on October 17, 2006.

Hastings Cove of Wachusett Reservoir and Common Reed (*Phragmites australis*)

A stand of Common Reed (*Phragmites australis*) encroaching on the southern shoreline of Hastings Cove (Boylston) was surveyed on July 19th and determined to cover an area of approximately 2,300 square feet. It has a roughly semicircular shape measuring about 120 feet along the shore and extending 38 feet out into water three feet deep (reservoir elevation = 390.6 feet). This infestation has gradually expanded over the years since first documented in 1999, but does not constitute a significant threat to water quality and is not considered a high priority for removal. This is the only stand of Common Reed encroaching on the shoreline of Wachusett Reservoir.

Sudbury Reservoir and Water Chestnut (*Trapa natans*)

As part of ongoing collaboration with MWRA, DCR staff conducted a preliminary macrophyte survey of Sudbury Reservoir on September 15th using an MWRA canoe at their invitation. A pioneer infestation of Water Chestnut (*Trapa natans*) was discovered in the extreme northern end of the reservoir adjacent to Marlborough and the inlet of Mowry Brook. This infestation consisted of two large patches 30 to 40 feet in diameter and four smaller patches. Prompt response by MWRA and the hand-harvesting contractor ACT resulted in the hand removal of these patches on September 29th with the biomass deposited on an adjacent small island. Complete results of the preliminary survey conducted by DCR are given in the table below. DCR will continue to scout for alien macrophytes in Sudbury Reservoir on an annual basis.

Macrophyte Flora of Sudbury Reservoir

Scientific Name	Common Name
Callitriche sp.	Water-starwort
Gratiola aurea	Golden-pert
Myriophyllum heterophyllum	Variable Water-milfoil (alien)
Myriophyllum spicatum	Eurasian Water-milfoil (alien)
Nymphaea odorata	White Water-lily
Pontederia cordata	Pickerel-weed
Potamogeton amplifolius	**Large-leaved Pondweed**
Potamogeton epihydrus	Leafy Pondweed
Potamogeton perfoliatus	Clasping-leaved Pondweed
Sagittaria graminea	Arrowhead
Trapa natans	Water Chestnut (alien)
Utricularia intermedia	Bladderwort
Vallisneria americana	**Tape-grass**
Wolffia sp.	Water-meal

Notes:
(1.) Dominant species indicated in **bold**.
(2.) Results based on visual observations conducted from a canoe on September 15, 2006.

4.5.4 PLANS FOR ALIEN CONTROL EFFORTS IN 2007

The invasive nature of milfoil and fanwort necessitate a long-term commitment to annual control efforts in the upper reaches of the Wachusett Reservoir system if their dispersal into the main basin is to be prevented. To meet this challenge, DCR and MWRA continue to work collaboratively to sustain annual control efforts and refine the control program as necessary.

Next year, during the 2007 growing season, plans call for a resumption of intensive hand-harvesting in Upper Thomas Basin. Early efforts will focus on harvesting plants in areas known to support regrowth of alien macrophytes and the few specimens not removed last season. Dive crews will conduct hand-harvesting at intervals throughout the summer to suppress regrowth that sometimes occurs subsequent to initial harvesting efforts.

Associated with hand-harvesting efforts, DCR staff will continue routine scouting for alien macrophytes throughout the reservoir system to identify and target any pioneering specimens found in new locations. Also, DCR staff will redeploy the floating fragment barriers at their strategic "bottleneck" locations as done in previous years.

5.0 SUMMARY OF SITE INVESTIGATIONS

A total of 120 new sites were investigated during 2006. A majority of the issues at these locations were related to residential development and resulted in problems with sedimentation and erosion, encroachment, or potential contamination. Construction projects included single family homes, small and large subdivisions, additions, swimming pools, and sheds. Other problems addressed during 2006 included spills of hazardous materials, road reconstruction and bridge replacements, wetland alteration, sewer and septic problems, stormwater runoff, and a variety of agricultural issues.

Problems at seventy-six of the sites were addressed during 2006 and are now considered resolved. Eight sites are currently on watch status. Work at these sites is being monitored and additional activities are necessary in some cases, but the OWM is confident that successful resolution of these issues will occur.

Thirty-six sites originally investigated during 2006 remain active. Twelve involve minor additions, garages, or pools, four are new subdivisions, and two are related to construction of single family homes. Three involve wetland disturbances and DCR staff are working with local conservation commissions towards resolution. There are two roadways issues currently under review including a bridge repair over the Stillwater River. There are five other construction related issues needing work, four stormwater problems, and single cases involving wildlife, agriculture, a sewage discharge, and a petroleum spill. There are locations from previous years that remain active as well, along with twenty-one investigations initiated during the first few months of 2007.

A large number of existing issues were addressed during 2006 and early 2007. Many of these simply required follow-up communication and documentation, while others needed additional investigation or actions. A total of 903 files currently exist; 755 issues have been resolved and less than one hundred remain active. All other files are on watch status.

6.0 SAMPLING PLAN FOR 2007

The Wachusett watershed sampling program for 2007 will once again include special studies, enforcement actions, incident response, and routine sampling and analysis. The routine sampling program will separate out the effects of storm events on tributary water quality from standard dry weather water quality data using detailed precipitation data from several stations in or near the watershed. The program was designed to protect public health, identify current and potential threats to water quality, and further our understanding of the reservoir and its tributaries.

Fecal coliform and conductivity will be measured weekly at fifty-four stations on thirty-one tributaries during dry weather. This is the fourth year of the expanded sampling program that collects data from a greater number of stations to be able to address issues that have been identified in previous water quality summaries and Environmental Quality Assessment reports. Quarterly nutrient samples will again be collected from nine tributary stations with available flow data. Separate wet weather sampling of eight major tributaries will be done to help quantify bacterial loading to the reservoir from storm events. Tributary sampling will take place immediately following rain events (first flush) and then the eight stations will be resampled after 24 and 48 hours to see how long elevated fecal coliform concentrations persist after a storm. Precipitation amounts and stream flows will all be carefully documented and compared to bacteria numbers to attempt to further refine our understanding of the causes of elevated fecal coliform levels in Wachusett tributaries. Further attempts will be made to relate seasonal effects on water quality responses to storm events.

Monthly temperature, dissolved oxygen, pH, and conductivity profiles will be taken at three reservoir stations (3417-Basin North, 3412-Basin South, and Thomas Basin) during ice-free periods using a Hydrolab H20 Sonde Unit and a Surveyor III data logger. More frequent profiles will be collected when necessary to document changing conditions in the reservoir. Plankton samples will be collected weekly or biweekly at multiple depths from the Cosgrove Intake or mid reservoir station 3417, and quarterly from Thomas Basin and mid reservoir station 3412. Samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, and both total and dissolved silica will be collected quarterly from 3417, 3412, and Thomas Basin. Fecal coliform bacteria samples will no longer be collected at the Cosgrove Intake by DCR. MWRA staff will continue to collect regulatory samples once per week from an internal tap and five days per week from the new water treatment plant in Marlborough.

The movement of water and contaminants through the reservoir, especially during times when water is being transferred to Wachusett Reservoir from Quabbin Reservoir, remains the focus of significant interest. Sampling of the reservoir surface will continue on a regular basis. Monthly, biweekly, or weekly bacterial transect sampling will be done during ice-free periods to help further understand the effect of water movement on fecal coliform levels throughout the reservoir. A consultant study of reservoir hydrodynamics currently underway should help improve our understanding of this important issue.

Sampling of the Pinecroft area drainage basin (Cook Brook) will continue as part of the routine weekly sampling program in order to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Samples will also be collected from two similar sized drainage areas with different land uses for comparative purposes. Additional areas in West Boylston and Holden that have recently been sewered will be examined again to see if improvements can be detected, and historical data will be analyzed to help detect any possible positive trends. 2007 is the final year of a ten year sampling period, and all water quality data from 1998-2007 will be reviewed to prepare a detailed summary and assessment and compare it with data from the previous ten-year period.

Additional sampling will be done as needed if water quality conditions change and problems are noted, and to help locate occasional sources of contamination. Samples will also be collected to support any potential enforcement actions required by other OWM staff. Several tributaries will again be the subject of intensive investigations to attempt to locate a persistent seasonal fecal coliform problem. Previous attempts have been only partially successful. A number of different methods will be used in 2007 including monitoring for optical brighteners, a continuation of alternative indicator sampling, and the possible use of genetic identifiers (in cooperation with University of Massachusetts researchers) to track dog contamination.

7.0 REFERENCES CITED:

EPA, 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents (C.I. Weber, editor) EPA-670/4-73-001.

Worden, David and Larry Pistrang. 2003. Nutrient and Plankton Dynamics in Wachusett Reservoir: Results of the MDC/DWM's 1998-2002 Monitoring Program, a Review of Plankton Data from Cosgrove Intake, and an Evaluation of Historical Records. Metropolitan District Commission, Division of Watershed Management.